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MEMORANDUM

From: Professor H. A. Titus, Department of Electrical Engineering
To: Curricular Officer, Aeronautical Engineering Programs

Subj: Confidential Thesis, "Investigation of Optimum Smoothing in a Track-While-Scan Radar Using Three Dimensional Simulation," by LT Richard C. Gentz, USN

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INVESTIGATION OF OPTIMUM SMOOTHING

IN A TRACK-WHILE-SCAN RADAR

USING

THREE DIMENSIONAL SIMULATION ~~(C)~~ (U)

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Richard C. Gentz

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IN A TRACK-WHILE-SCAN RADAR

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THREE DIMENSIONAL SIMULATION (U)

by

Richard C. Gentz

Lieutenant, United States Navy

Submitted in partial fulfillment of
the requirements for the degree of

MASTER OF SCIENCE
IN
AEROELECTRONICS

United States Naval Postgraduate School
Monterey, California

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INVESTIGATION OF OPTIMUM SMOOTHING IN A TRACK-WHILE-SCAN RADAR USING THREE DIMENSIONAL SIMULATION ~~(C)~~ (U)

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This work is accepted as fulfilling

the thesis requirements for the degree of

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[redacted]

ABSTRACT

The α, β, γ tracker system of optimal smoothing was investigated in a track-while-scan radar by using three dimensional simulation of various interceptor-target profiles. Random noise was put on all parameters which were not positively defined. This included the target's motion.

The computer program used is designed for carrying on the analysis with other systems so that their performance can be compared with the α, β, γ tracker. A number of representative profiles are listed which should provide a suitable basis for evaluation of any chosen alternate system.

The parameters used in the analysis are similar to those which will be used in the Hughes Aircraft Co. developed AWG-9, Phoenix, Aircraft Missile Control System designed for the F-111B aircraft.

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TABLE OF SYMBOLS

α : Position smoothing constant.

β : Velocity smoothing constant

γ : Acceleration smoothing constant.

ϵ : Antenna elevation angle.

η : Antenna azimuth angle.

Θ : Interceptor Pitch angle.

λ : General parameter to be smoothed.

σ : Standard deviation of normally distributed random noise.

ϕ : Interceptor roll angle.

ψ : Interceptor heading angle.

N : North direction cosine.

E : East direction cosine.

D : Down direction cosine.

T : Frame time.

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1. Introduction

The α, β sampled data system has been the most often proposed means of performing the task of optimum smoothing in a track-while-scan radar. This method is particularly attractive since it is very simple. However, in the light of the high performance intercept problems which may be encountered today, especially by a high performance aircraft, it was felt advisable to investigate the capabilities of such a smoothing system in the environment of air-to-air intercepts.

In this analysis the third order system or α, β, γ tracker was considered by using a three dimensional simulation of various interceptor-target profiles. Random noise was placed on all the parameters which were not positively defined. This included the motion of the target.

The computer program used was designed for carrying on the analysis with other systems so that their performance could be compared with that of the α, β, γ tracker.

The parameters used in the analysis were similar to those which will be used in the Hughes Aircraft Company developed AWG-9, Phoenix, Aircraft Missile Control System. This system is currently being developed for use in the F-111B aircraft.

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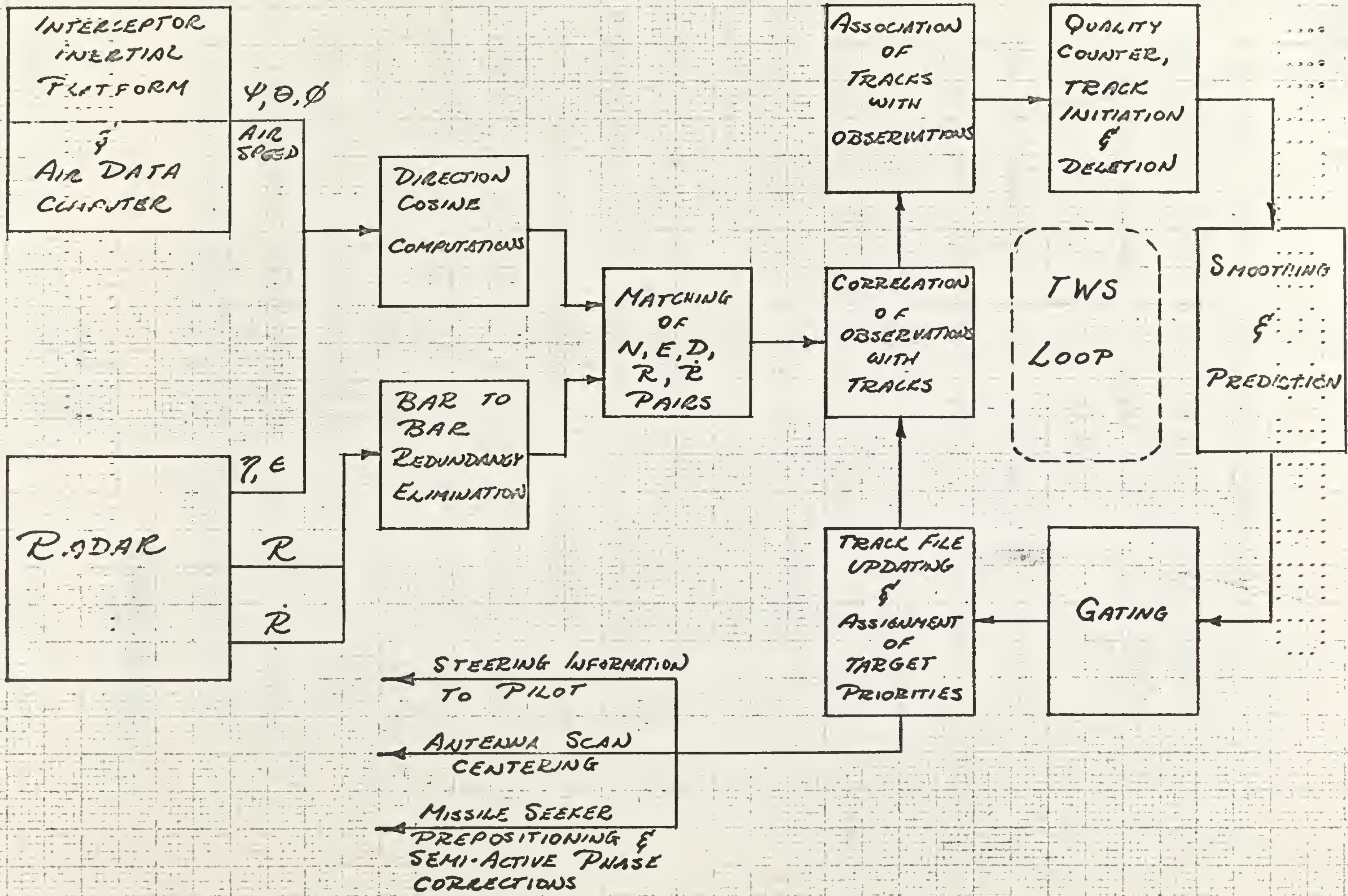
2. Basic System Description

The system considered in the analysis was a pulse doppler radar operating in a track-while-scan mode, TWS. That is, the radar was able to obtain simultaneously at discrete sampling intervals, called frame times, the target's range, range rate, and bearing, in azimuth and elevation, relative to an interceptor's antenna. At the same time the system was also maintaining a track file on a number of other targets at locations spaced over its scan volume.

The heart of a system such as this is the so-called "track-while-scan loop." Fig. 1 is a basic block diagram of this loop.

Prior to entering the TWS loop the raw A to D converted parameters are taken from the output of the radar, and the interceptor's inertial reference platform and air data computer. This information is pre-processed to remove any redundancies caused by picking up the same target on two or more antenna sweeps, called bars. Also the north, east, down direction cosines are computed. These are the direction cosines for a north, east, down axis coordinate system which is fixed to the interceptor. The axes are defined by having the north axis pointing toward true north. The east axis results from the cross product of the

FIG. 1
Track-While-Scan Loop
Block Diagram



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down and north axis. The down axis points towards the earth's local vertical, and is positive downward. Thus an interceptor flying north would have the north axis along the line of sight, the east axis out the right wing and the down axis vertically downward.

The data now enters the "track-while-scan loop." It is first correlated by having the individual observations checked against previous tracks on file in memory. This may result in several observations being linked with one track. These are then associated by having the observations paired by a logic routine with the track which it most closely matches. The next stage initiates new tracks or deletes old tracks, which no longer associate after a quality counter, which rates each track, degenerates to a point such that the track no longer warrants being maintained on file.

The next section and the one which is investigated in this paper is that of smoothing and prediction. The ability of the system to perform all previous and following tasks rests on how well the track is smoothed, i.e., the effect of noise removed, and how well it predicts the target's future motion. This section must be designed to respond quickly to target maneuvers while filtering out the false excursions of the target caused by noise so that future predictions will be as accurate as possible.

The gating section is next in the loop. It is this section which determines the possible limits of target motion between contacts. It allows for target maneuvers between scans plus approximately 3σ noise. It further provides for expansion in the event of a missed contact. A maximum gate size is imposed which corresponds to a volume which would contain any possible target maneuver that could occur up to the time the track would normally be eliminated by the quality counter due to missed contacts.

The individual track parameters are stored in the track file section to keep it updated. These along with the track locations are used to determine target priorities. The track parameters are also used to determine which observations correlate with the tracks during the correlation phase at the beginning of the loop. The above computations are performed on all tracks at the end of each frame time.

Additional functions which result from the TWS loop computations are the antenna scan center calculations to keep the pattern centroid located in the center of the incoming raids, the steering information to the pilot to allow him to maneuver as necessary to keep the radar within its gimbal limits, prelaunch information to the missile so that its seeker head is oriented in the proper position at the beginning of its semi-active phase,

and midcourse maneuver corrections to the missile during flight.

It is readily apparent that the system must be optimized to the highest possible degree in light of the high relative speeds encountered and the number of targets to be tracked. At the same time it is extremely important that computations remain relatively simple to maintain reliability and to keep computational time and storage space to a minimum.

The ability of the system to meet these criteria lies primarily in the smoothing, prediction and gating sections. It is the former two which are considered in this paper.

3. System Characteristics

The values of the system performance parameters were derived primarily from the Hughes SYSTEM EVALUATION AND ANALYSIS REPORT, SEAR, [1]. Where possible these parameters have been crossed checked with other company internal documents, or by conversations directly with company engineers. The following parameters and assumptions are those which were used in the simulation.

It was assumed that the interceptor would have an on station Mach number of 0.7 at above 36,000 feet. The target's speed was believed to be between Mach 0.4 and 3.0 and its altitude could be between sea level and 80,000 feet.

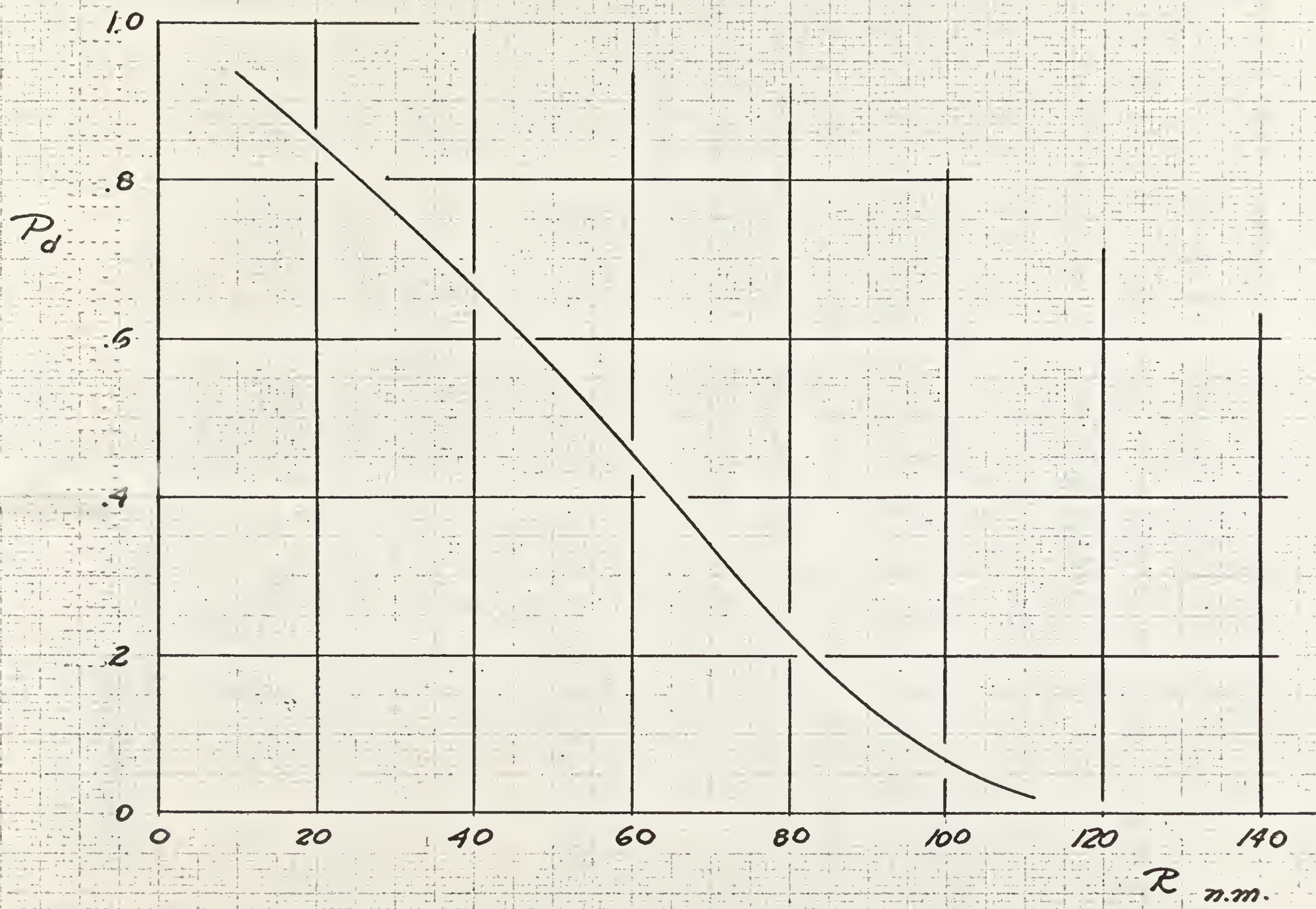
The general characteristics of the radar were those of a high PRF pulse doppler using linear frequency modulation.

The detection range was 165 n.m. This was defined as the range where S/N was one using the classic radar range equation. It was based on a five square meter target. The radar's probability of detection curve is shown in Fig. 2.

The effect of clutter on detection probabilities was not considered since a large amount of clutter rejection is an inherent advantage of a high PRF pulse doppler radar. This is particularly true over water. In addition

[redacted]

FIG. 2
Probability of Detection



[redacted]

the system will also have clutter rejection circuitry. Due to the high PRF certain relative velocities may cause periodic loss of signal due to "eclipising", i.e., target echo returning during pulse transmission. Multiple PRF rates will normally remove this possibility. Thus eclipising was not considered to effect detection probability.

In the radar, range is measured by taking the difference between two filters in a doppler filter bank that are "rung" on successive FM phases. The spacing of the filters corresponds to five n.m. Since there are 30 filters the range can be measured to 150 n.m. The signal was considered to originate uniformly in plus or minus one-half a filter and terminate normally distributed with a standard deviation of one-third a filter. This is shown in Fig. 3.

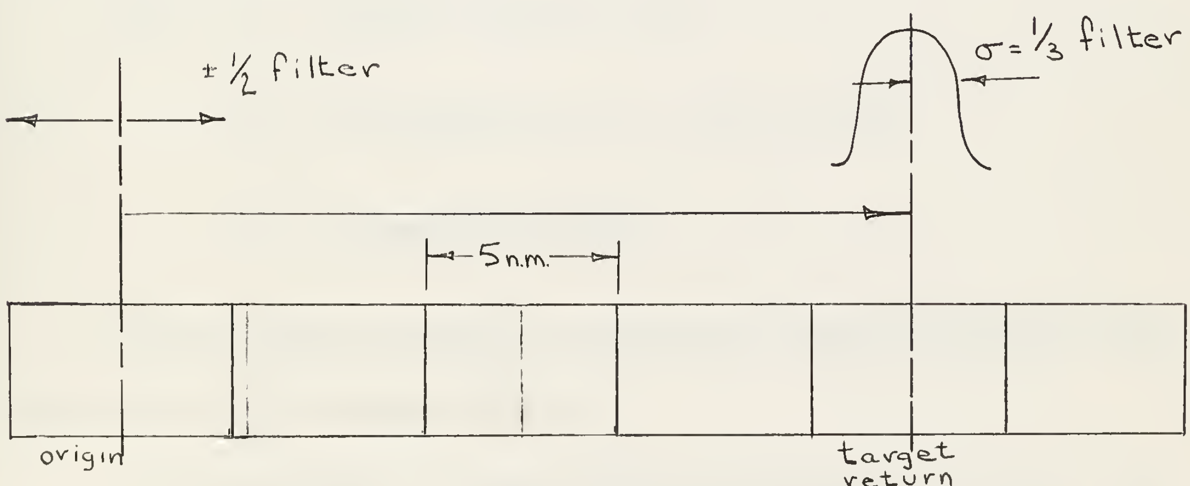


Fig. 3

Probability Distribution of Range Measurement

Hughes stated that a joint distribution describing these two distributions yielded a normal distribution of zero mean and standard deviation of 1.37 n.m. It was felt that this value was too optimistic and indicated that the distributions were quite dependent, i.e., the covariance was large. The value used for the range standard deviation in this analysis was 2.5 n.m.

Range rate is measured by frequency shift as determined by a doppler filter bank. The filters are spaced 150 cps apart. Thus at X band using the equation given by Skolnik [2]:

$$V_r = \frac{f_d \lambda}{103} .$$

Where: f_d = doppler frequency shift.

λ = wavelength in cm., 3 cm at X band.

V_r = range rate in knots.

The total number of filters is 768 giving the ability to measure range rates of up to approximately 3250 kts.

It was determined by Hughes that the distribution of the range rate error was normal with zero mean and a standard deviation of two filters, 8.72 kts.

The scan pattern of the antenna in the TWS mode is either two bar $\pm$ 40 deg. or four bar $\pm$ 20 deg. The beam separation is 1.32 deg. and the scan rate is 40 deg/sec. It was determined from various sources that the average antenna azimuth error could be considered normally distributed with zero mean and standard deviation of 0.745 deg. Similarly the elevation error had zero mean and standard deviation of 0.86 deg. These values include radome, potentiometer output, and pick off errors. The additional error in elevation is due primarily to the introduction of redundancies caused by picking up the same target on two separate scans.

The smoothing and prediction system which has been proposed by Hughes is the α, β, γ tracker type. The characteristics of this system are considered in the following section.

4. Smoothing System Discussion

Since computational time and storage space available for smoothing and prediction is quite limited some of the more sophisticated smoothing systems would not at first appear to be suitable for use in the system described. The requirements of the system are reduced somewhat, however, by the fact that the target's capabilities are relatively predictable, but of course, entirely random. For these reasons the most attractive choice is an α, β tracker type of system. Almost any other system that would be acceptable would reduce to a scheme which would use a similar smoothing constant gain technique in any case.

The α, β, γ tracker system is an extension of the α, β tracker to allow for the smoothing of acceleration. As given by Benedict and Bordner [3] the variance reduction ratio is optimized by having the velocity constant, β, defined as:

$$\beta = \frac{\alpha^2}{2-\alpha} .$$

Similarly it was shown by Simpson [4] that when acceleration was considered the optimum value of the acceleration smoothing constant, γ, became:

$$\gamma = \frac{2\beta}{\alpha} - (\alpha + \beta) .$$

[redacted]

Thus if it is possible to define α the smoothing equations become unique.

The proposed equations used for the smoothing and prediction are:

A. Range:

$$
\begin{aligned}
R_{s_n} &= R_{p_n} + \alpha\left(R_n - R_{p_n}\right) \\
\ddot{R}_n &= \ddot{R}_{(n-1)} + \frac{1}{qT}\left(\dot{R}_n - \dot{R}_{p_n}\right) \\
R_{p(n+1)} &= R_{s_n} + T\dot{R}_n + \frac{T^2}{2}\ddot{R}_n \\
\dot{R}_{p(n+1)} &= \dot{R}_n + T\ddot{R}_n
\end{aligned}
$$

Where:

$R_n = R_{o_n}$ and $\dot{R}_n = \dot{R}_{o_n}$ if an observation was received.

$R_n = R_{p_n}$ and $\dot{R}_n = \dot{R}_{p_n}$ if an observation was missed.

T = Frame Time = 2 ± 0.1 sec.

q = Number of frame times since last value of range rate was received.

The subscripts are:

n = Frame number.

p = Predicted.

o = Observed.

s = Smoothed.

[redacted]

The value of α for range smoothing as proposed by Hughes was 0.45. Since the standard deviation of range rate was relatively small no smoothing of range rate was necessary so that no β, or γ were required in range smoothing.

B. Direction Cosines:

$$\Lambda_{sn} = \Lambda_{pn} + \alpha(\Lambda_n - \Lambda_{pn})$$
$$\dot{\Lambda}_n = \dot{\Lambda}_{(n-1)} + T\ddot{\Lambda}_{(n-1)} + \frac{\beta}{T}(\Lambda_n - \Lambda_{pn})$$
$$\ddot{\Lambda}_n = \ddot{\Lambda}_{(n-1)} + \frac{2\gamma}{T^2}(\Lambda_n - \Lambda_{pn})$$
$$\Lambda_{p(n+1)} = \Lambda_{sn} + T\dot{\Lambda}_n + \frac{T^2}{2}\ddot{\Lambda}_n$$

Where:

$\Lambda_n = \Lambda_{on}$ if an observation was received.

$\Lambda_n = \Lambda_{pn}$ if an observation was missed.

Λ = general direction cosine being smoothed.

For the North and East direction cosines, N, E, Hughes proposed the smoothing constant values of:

$\alpha = 0.43$

$\beta = 0.120$

$\gamma = 0.008.$

For the down direction cosine, D, the proposed values were:

$\alpha = 0.35$

$\beta = 0.075$

$\gamma = 0.0035.$

A Z- transform analysis of the α, β Tracker was performed by Sklansky [5]. Basically the system is stable and for a non-maneuvering target there would be no steady state error for α between zero and one. When α is equal to one no smoothing would be performed and raw data would be the output. In a high noise non-maneuvering target condition the smoothing constant would be small and the system response would be slow. For increasingly lower noise the smoothing constant would approach one in the limit. For a maneuvering target the smoothing response must be increased so that a larger value of α is required.

The obvious disadvantage of the α, β Tracker is that there is not a single optimum value of the smoothing constant for all the situations that can be encountered.

The advantage of the system again lies in its simplicity and the small number of computations and amount of storage space required. Also, since β and γ are defined uniquely when α is determined the problem of fixing the constants is reduced somewhat.

5. Simulation

The CDC 1604 computer was used to implement the three dimensional simulation of a single target-interceptor problem. This program was named Three D. The primary aims of the simulation were to provide realistic, flexible and accurate target-interceptor geometries. The pseudo random noise generator, sub routine RNDEV, was used to provide gaussian noise on all parameters that were not positively defined.

A list of symbols and a description of the use of the programs used are contained in Appendices A and B.

The resulting program allowed the target to be positioned initially at any location in the northern half of a north, east, down coordinate system which was ground stabilized at the interceptor's initial location at problem time zero. The target's initial coordinates, maneuver parameters, and maneuver times were then read in by data cards along with the interceptor's heading, altitude, and Mach number. The interceptor's velocity was computed in the program by using the following relation:

$$V_{fps} = \text{Sonic Velocity}_{fps} \times \text{Mach Number}.$$

The variation of the speed of sound with altitude is shown in Fig. 4.

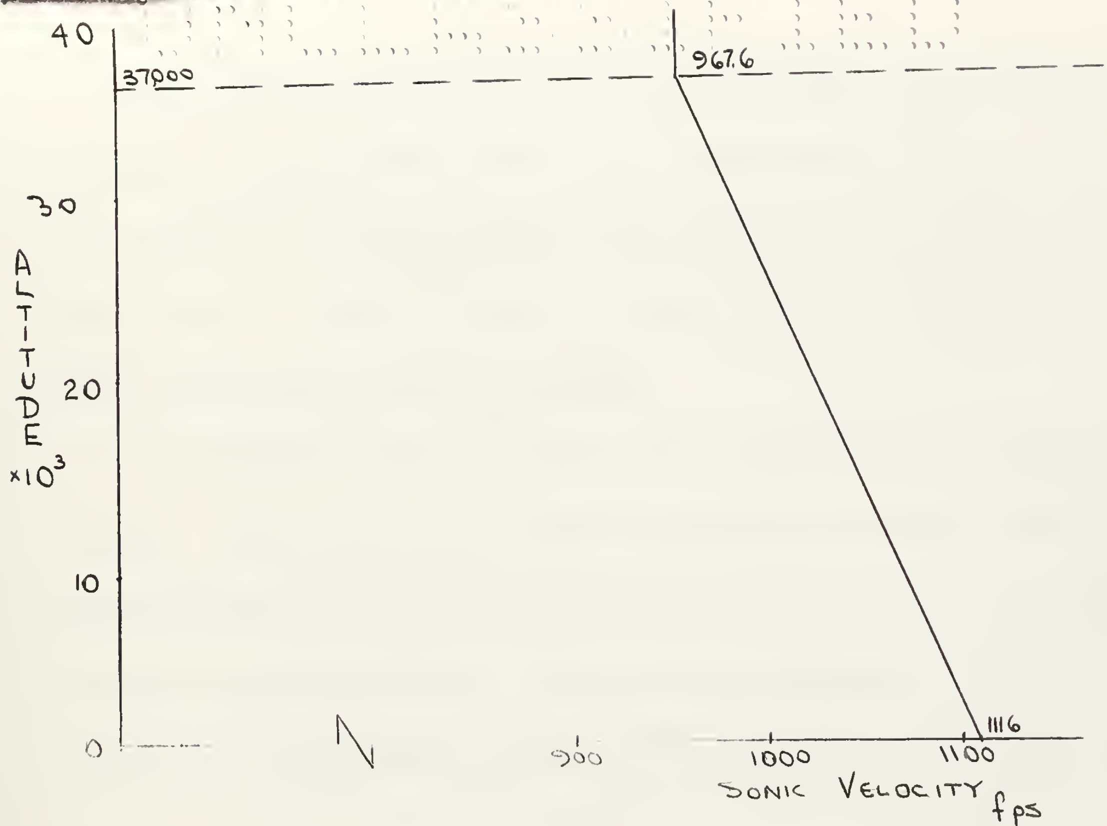


Fig. 4.

Speed of Sound Versus Altitude

No provision was included to maneuver the interceptor since one of the basic assumptions of the system was that the interceptor was continually tracking several targets in widely spaced locations in the radar's scan pattern. It was thus not possible for the pilot to place an individual target in the center of the scan. Also no random noise was used to vary the interceptor's position since the same relative effect was gained by randomly varying the target's velocity components.

The problem time was taken to be 300 seconds. This allowed a target at Mach 1.5 above 36,000 feet to travel slightly over 70 n.m. in the course of the problem. Since the probability of acquiring and tracking a target beyond 100 n.m. was very low, 100 miles could be considered the range limit in setting up the problem profile.

The target's velocity was also determined by the previously mentioned relations. No provision was made to accelerate the target, but the target would decelerate at the start of its dive. Its final speed was a function of altitude below 10,000 feet. The minimum speed was Mach 1.2, 1340 fps. at sea level. The relations used are shown in Fig. 5. The target was

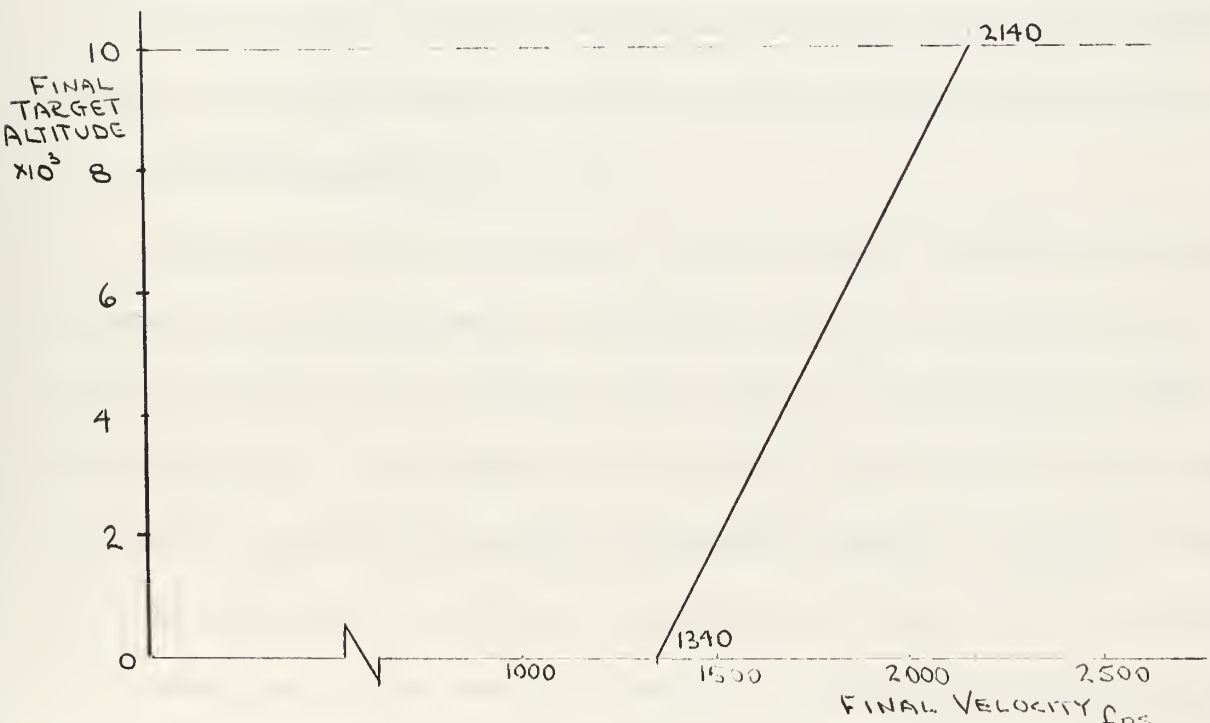


Fig. 5.

Final Target Velocity Below 10,000 Feet

programmed to make a 180 degree turn at a programmed time and horizontal turn g load. It would also make a 60 degree dive and pull out at a programmed time, final altitude, positive and negative g factor.

For convenience, distances were read in, in nautical miles, velocities in Mach number, and headings in degrees. The program then converted the values to compatible units of ft., ft./sec., and radians.

The motion of the target was computed by piece-wise-linear integration. Random accelerations having a standard deviation of one-half g for two second periods were imposed. The target's motion was broken down into velocity, VT, along its path of flight, heading angle, AT, and pitch angle, BT. Each component was then related to the distance traveled in each of the coordinate axes in the iteration time and combined with the previous position to give the new target location, XT, YT, ZT.

Every two seconds of problem time the target's coordinates were taken, compared with the interceptor's coordinates XO, YO, ZO and the actual antenna azimuth, ATA, elevation, EPSI, range, R, and range rate, RDOT were computed. If the target had passed out of the limits of the radar beam, + 65 degs. in azimuth and elevation the problem stopped. It should be noted that the antenna does not have a scan volume this large in the track while scan mode, but it does have the capability of positioning its scan anywhere inside these limits.

The random noise generator was then used to put noise on the radar parameters, ATAE, EPSIE, RE, and RDOTE, and the apparent target location having coordinates XTE, YTE, and ZTE, was determined. Since a relatively small number of samples were used the mean, variance and independence of the noise for each of the parameters were checked using an autocorrelation routine. The results of analysis are shown in Table I.

The actual and noisy direction cosines for the three axes were then computed. These were, north direction cosine, DIRN, and DIRNE, east direction cosine, DIRE and DIREE, and down direction cosine, DIRD, and DIRDE.

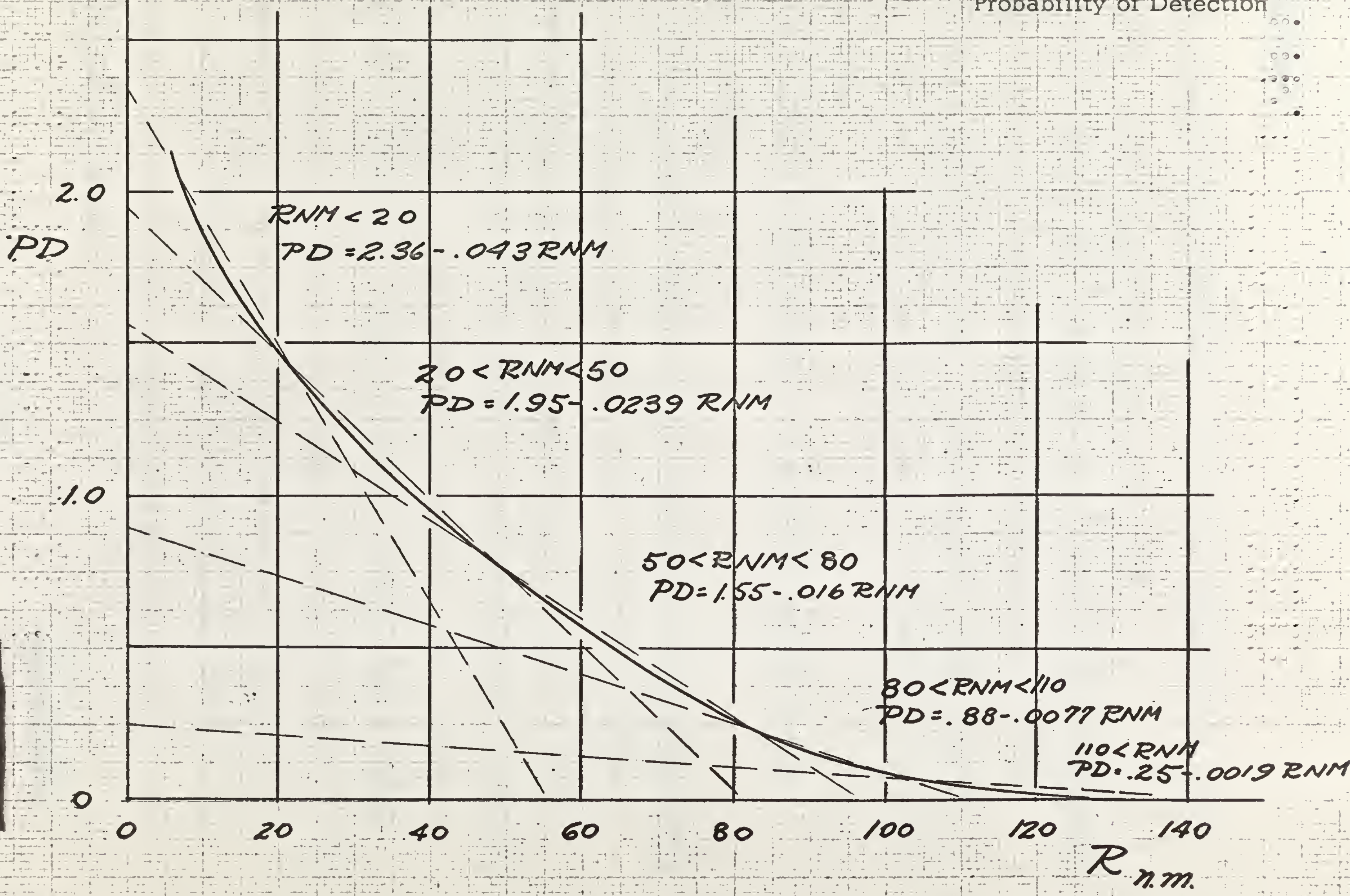
Knowing the probability of detection of the radar, RNDEV was used to determine a zero-one probability of detection for each frame time. This was done by cross plotting the absolute value of the deviation required, versus range, corresponding to the probability of detection curve, Fig. 2. This was then made piece wise linear and implemented by using IF statements. Thus for each actual range a maximum value of deviation for detection could be determined, if the absolute value of DEV obtained from RNDEV exceeded this value no return for that frame time was assumed. Fig. 6 illustrates the method used.

TABLE I

AUTOCORRELATION ANALYSIS RESULTS OF PROGRAM THREE D (151 SAMPLES)

	Mean	Variance	Largest Value of Autocorrelation
RN 1 Target Acceleration Noise	0.0112	.772	0.1787
RN 2 Target Heading Acceleration Noise	-0.001	1.0636	0.1706
RN 3 Target Pitch Acceleration Noise	-0.1032	0.9585	0.2358
ATA Antenna Azimuth Noise	0.0785	0.9612	0.1717
EPSI Antenna Elevation Noise	0.6308	1.0433	0.1576
R Radar Range Noise	0.1386	0.9938	0.1721
RDOT Radar Range Rate Noise	0.1114	0.9780	-0.1528
PD Radar Probability of Detection Noise	-0.0564	0.9914	-0.1468

Figure 6
Normal Curve Adapted To Provide
Probability of Detection



[redacted]

In the actual system this would be the status of the individual track in the TWS loop after being correlated and associated.

A quality counter, NQ, was devised for the program which incremented in steps of two for each received return to a maximum of ten. For each missed return it degenerated by one. When the quality counter reached zero the track was dropped and no smoothing was performed until the next received return.

The particulars of the smoothing and prediction section were as described earlier.

The primary quality indicator for the system was the three dimensional rms smoothed difference from the actual position. Since high relative velocities between the missile and the target are considered very likely in the active phase of the missile flight it is necessary that the missile be positioned accurately at the beginning of this period so that its maneuvers may be kept to a minimum. In order to assist in achieving this a desired rms smoothing error limitation of approximately one-half mile inside 50 miles was imposed. On the output curves points were plotted indicating these limits. For range constant lines of points at plus or minus one-half mile were plotted. For azimuth and elevation points were plotted as a function of range using the relation:

$$\text{Angular error Maximum} = \text{ARCTAN} \frac{0.5}{\text{RNM}.}$$

If all the parameters were smoothed to the desired value the three dimensional rms error, CIRSMO, could be as high as 0.875n.m. Thus on the curves of CIRSMO a line of points having this value were plotted.

The program print out contained the run number, problem time, actual range, rms three dimensional actual error, CIRERR, rms three dimensional smoothed error, CIRSMO, a one or zero for detection or no detection, ND, and the status of the quality counter, NQ. When the quality counter was zero no contact was assumed and all nines were printed out.

To observe the results of the smoothing method the sub-routine CALL DRAW was used to plot the interceptor and target positions in the north-east, N-E, plane, looking down from above, and the north-down, N-D, plane, looking in from the east axis. The subroutine was also used to plot the difference between the actual and smoothed values of range and the direction cosines, which were plotted as angular differences, and the values of the three dimensional rms smoothed error.

6. Results of the Analysis of the Proposed System

Table II contains the important details of the problem profiles used in the analysis. The results of run 1A are shown in Table III and Figures 7 to 15. The results of runs 2A and 3A are shown in Appendix D.

Three basic profiles were considered. These were identified by the initial position and heading of the target with respect to the interceptor. For run 1 the target was positioned at 100 n.m. and was closing the interceptor. For run 2 the target was positioned at 10 n.m. and was moving away from the interceptor. In run 3 the target was positioned at approximately 60 n.m. at a 30 degree angle from the interceptor and was headed on a cross track with respect to it. The actual profiles flown by the target and the interceptor could be varied in a myriad of ways, however in reaching the conclusions that follow only those flight paths shown in Table II were used.

The results obtained for the system, as proposed by Hughes, indicated that the smoothed tracks were still quite noisy. The direction cosine smoothing results obtained by analyzing the figures of these values compared to the desired limits indicated that the direction cosines were being smoothed inside the limits rather well. Some degradation was noted in the cross track cases

TABLE II

FLIGHT PROFILES USED IN ANALYSIS

TARGET

Run Number	INITIAL PARAMETERS					Final	TIME TO	
	Nnm	Enm	D ft (above S.L.)	$Heading_{deg}$	Mach No	$Altitude_{ft}$	$Turn_{sec}$	$Dive_{sec}$
1 A	100	-10	40,000	180	2.5	1000	150	150
B						40,000	None	None
C						40,000	150	None
2 A	10	-10	40,000	360	2.5	1000	150	150
B						40,000	None	None
C						40,000	150	None
3 A	50	-40	40,000	090	2.5	1000	150	150
B						40,000	None	None
C						40,000	150	None

Note: Target maneuver capabilities are: Turn 6_g, Dive -3_g, and Pull Out 6_g.

INTERCEPTOR

$Heading_{deg}$	Mach No	$Altitude_{ft}$
350	0.7	37,000

[redacted]

SMOOTHING RESULTS

RUN 1A

T=TIME, R NM=ACTUAL RANGE, CIRERR=3DIMENSIONAL RMS ACTUAL ERROR, CIRSMO=3 DIMENSIONAL RMS SMOOTHED ERROR, ND=1 DETECTION, ND=0 NO DETECTION, NQ=QUALITY COUNTER, WHEN NQ=0 TARGET CONSIDERED LOST AND ALL NINES ARE PRINTED.

T	R NM	CIRERR	CIRSMO	ND	NQ
.	100.5000	999.9999	999.9999	99	0
2.	99.4871	999.9999	999.9999	99	0
4.	98.4809	999.9999	999.9999	99	0
6.	97.4805	2.8089	2.8089	1	2
8.	96.4819	.3501	2.7924	0	1
10.	95.4829	999.9999	999.9999	99	0
12.	94.4808	999.9999	999.9999	99	0
14.	93.4664	999.9999	999.9999	99	0
16.	92.4470	999.9999	999.9999	99	0
18.	91.4370	999.9999	999.9999	99	0
20.	90.4195	999.9999	999.9999	99	0
22.	89.3964	999.9999	999.9999	99	0
24.	88.3717	999.9999	999.9999	99	0
26.	87.3507	999.9999	999.9999	99	0
28.	86.3438	2.1180	2.1180	1	2
30.	85.3354	1.6702	2.0969	0	1
32.	84.3289	999.9999	999.9999	99	0
34.	83.3276	3.9403	3.9403	1	2
36.	82.3209	2.5368	3.9162	0	1
38.	81.3087	.7825	2.4350	1	3
40.	80.2970	3.2225	2.3204	0	2
42.	79.2848	.9345	2.2242	0	1
44.	78.2667	999.9999	999.9999	99	0
46.	77.2543	2.7971	2.7971	1	2
48.	76.2567	2.4162	2.8147	0	1
50.	75.2688	999.9999	999.9999	99	0
52.	74.2774	999.9999	999.9999	99	0
54.	73.2785	999.9999	999.9999	99	0
56.	72.2763	.7391	.7391	1	2
58.	71.2801	3.5905	1.1076	1	4
60.	70.2918	2.9569	1.2629	0	3
62.	69.2966	1.8983	1.4499	0	2
64.	68.2990	2.9966	1.5692	1	4
66.	67.3133	.3755	.7502	1	6
68.	66.3347	3.4902	.7604	0	5
70.	65.3566	2.4328	.7920	0	4
72.	64.3877	2.9470	1.6471	1	6
74.	63.4255	4.4218	1.7263	0	5
76.	62.4593	4.4005	1.8257	0	4
78.	61.4952	.8885	1.9355	0	3
80.	60.5331	.8715	1.1710	1	5
82.	59.5727	3.2183	1.2012	0	4
84.	58.6241	6.4126	1.2271	0	3
86.	57.6929	1.9297	1.2447	0	2
88.	56.7703	1.5748	1.2605	0	1
90.	55.84[illegible]5	2.2930	1.6465	1	3
92.	54.9099	1.0705	1.3791	0	2
94.	53.9813	4.2629	1.7212	0	1
96.	53.0444	999.9999	999.9999	99	0
98.	52.1038	2.9109	2.9109	1	2
100.	51.1811	2.3925	2.8871	0	1
102.	50.2683	1.2764	2.1161	1	3

[redacted]

104.	49.3610	1.1716	2.1280	0	2
106.	48,4660	1.3300	2.1478	0	1
108.	47,5685	2,5272	.6311	1	3
110.	46,6623	1.6322	.7560	0	2
112.	45,7441	1.1995	.6104	1	4
114.	44,8141	2.4284	1.0049	1	6
116.	43,8711	2,8101	1.7097	1	8
118.	42,9232	2,0857	1.6194	1	10
120.	41,9624	1.6084	.9878	1	10
122.	40,9986	3,9664	1.5656	1	10
124.	40,0442	3,5859	.9143	1	10
126.	39,0998	1,0404	.8934	1	10
128.	38,1587	2,5277	.9466	0	9
130.	37,2168	4,0934	1.6227	1	10
132.	36,2832	3,0987	1.6066	0	9
134.	35,3557	3,7174	1.5809	0	8
136.	34,4268	1.4977	.3722	1	10
138.	33,4964	4,4075	.4850	0	9
140.	32,5567	1,4627	.6428	1	10
142.	31,6179	3,3400	1.8072	1	10
144.	30,6886	4,5131	1.1939	1	10
146.	29,7558	2,1345	1.4976	1	10
148.	28,8093	,9501	1.1917	1	10
150.	27,8563	1,1226	.8273	1	10
152.	26,8896	,7536	.6589	1	10
154.	25,9816	3,1620	.8572	0	9
156.	25,1572	5,4788	2,5853	1	10
158.	24,4380	4,1105	.9185	1	10
160.	23,8445	1,8564	.6228	1	10
162.	23,3933	3,3222	1.5404	1	10
164.	23,0952	5,0620	1.9082	1	10
166.	22,9552	,9599	1.7909	1	10
168.	22,9707	5,6214	2.4656	0	9
170.	23,1315	,3130	1.8425	1	10
172.	23,4222	1,0723	1.8749	1	10
174.	23,8221	1,1368	2,6427	0	9
176.	24,3080	4,4560	.2192	1	10
178.	24,8556	3,1212	1.1249	1	10
180.	25,4395	4,2445	2.2379	1	10
182.	26,0370	,5878	1.1206	1	10
184.	26,6251	2,1740	1.1881	0	9
186.	27,1849	2,3486	1.2085	1	10
188.	27,6986	2,4025	1.8340	1	10
190.	28,1555	,6367	2.0981	0	9
192.	28,6017	1,5670	1.8206	1	10
194.	29,0530	,7293	.8247	1	10
196.	29,5092	,3101	.3816	1	10
198.	29,9700	2,6407	.3614	0	9
200.	30,4338	,8438	.4553	1	10
202.	30,9019	2,0573	1.0997	1	10
204.	31,3732	1,6566	1,2539	1	10
206.	31,8487	2,2964	1,2489	0	9
208.	32,3273	3,7707	2,3333	1	10
210.	32,8086	3,1324	2.6509	1	10
212.	33,2933	1,0363	1.0451	1	10
214.	33,7606	1,5452	1.1826	1	10
216.	34,2715	1,3069	1.1601	0	9
218.	34,7654	,5480	1.1220	0	8
220.	35,2606	1.0041	.3621	1	10
222.	35,7582	2,1422	.7419	1	10
224.	36,2585	1.3269	1.0007	1	10

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TABLE III

226.	36.7614	2.1929	.6306	1	10
228.	37.2662	.4203	.5070	1	10
230.	37.7737	1.4021	.8871	1	10
232.	38.2827	2.2209	.8915	0	9
234.	38.7943	2.7467	1.6487	1	10
236.	39.3069	3.7272	.7716	1	10
238.	39.8210	.9506	.5839	1	10
240.	40.3378	.8783	.7262	1	10
242.	40.8568	2.7186	1.1963	1	10
244.	41.3762	6.0221	1.2214	0	9
246.	41.8975	1.1427	1.2499	0	8
248.	42.4203	3.5265	1.2827	0	7
250.	42.9449	.9221	1.0891	1	9
252.	43.4704	2.2873	.5461	1	10
254.	43.9969	1.0963	.2977	1	10
256.	44.5255	3.2416	1.3572	1	10
258.	45.0546	4.0951	1.1909	1	10
260.	45.5847	4.3770	1.2842	0	9
262.	46.1162	3.1601	1.8915	1	10
264.	46.6486	2.8110	2.2411	1	10
266.	47.1817	3.2857	.3059	1	10
268.	47.7164	5.9780	2.6170	1	10
270.	48.2523	1.3971	1.9555	1	10
272.	48.7889	3.5075	.7339	1	10
274.	49.3267	3.3489	.8322	0	9
276.	49.8658	.4459	.4249	1	10
278.	50.4053	1.0606	.6642	1	10
280.	50.9456	3.8362	2.0458	1	10
282.	51.4871	4.9476	1.1952	1	10
284.	52.0292	.8078	.5816	1	10
286.	52.5722	1.3545	.6306	0	9
288.	53.1158	1.9762	.9642	1	10
290.	53.6600	4.8418	1.0683	0	9
292.	54.2052	1.8616	1.1776	0	8
294.	54.7504	2.3180	1.2917	0	7
296.	55.2968	1.1498	.6087	1	9
298.	55.8440	2.4983	.6028	0	8
300.	56.3915	1.6145	.6383	0	7

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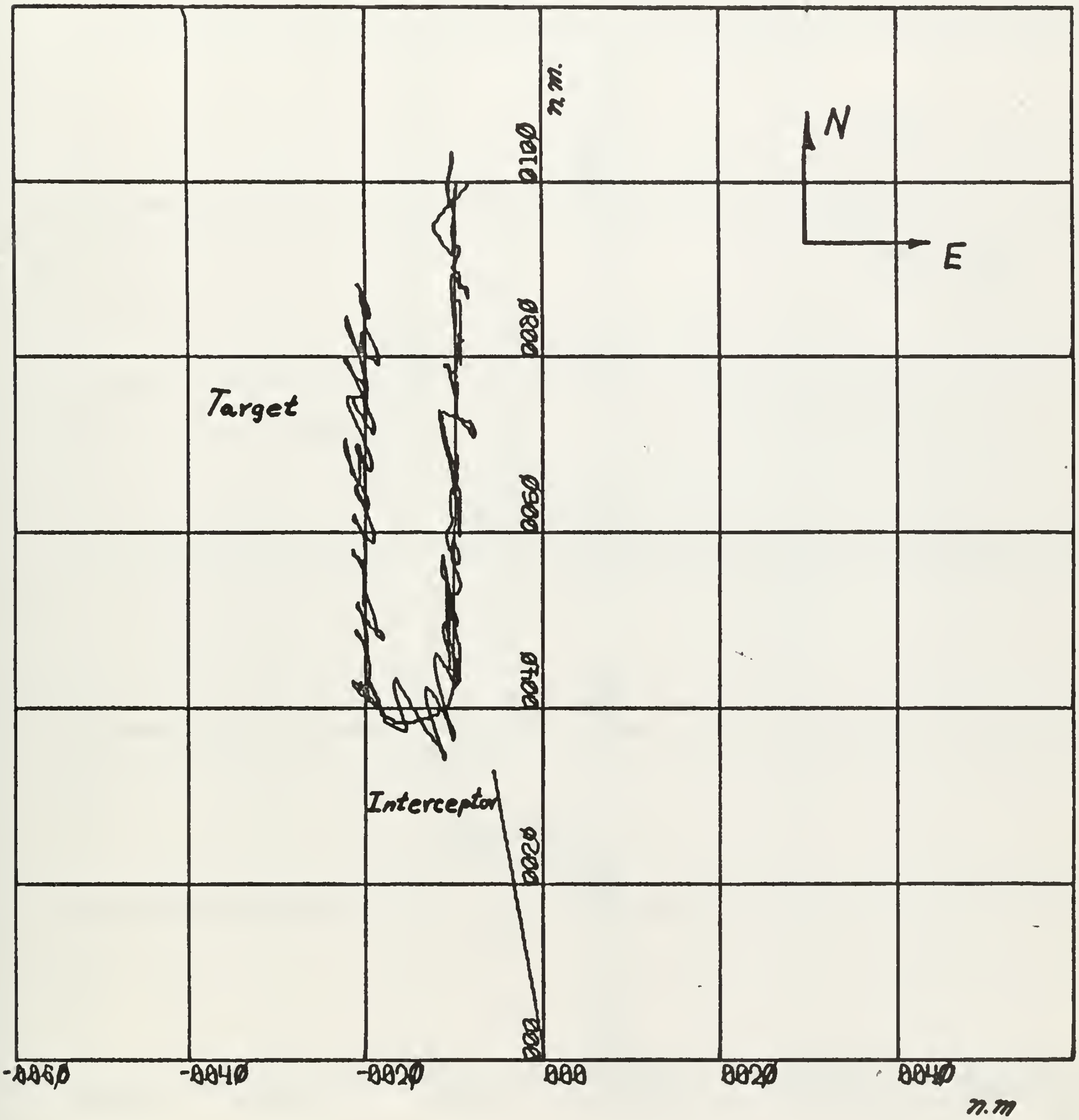
FIGURE 7



X-SCALE = 2.00E+01 UNITS/INCH.
Y-SCALE = 2.00E+01 UNITS/INCH.

CENTZ NE PLANE ACTUAL + NOISE ; RUN 1A

[redacted]

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[redacted]

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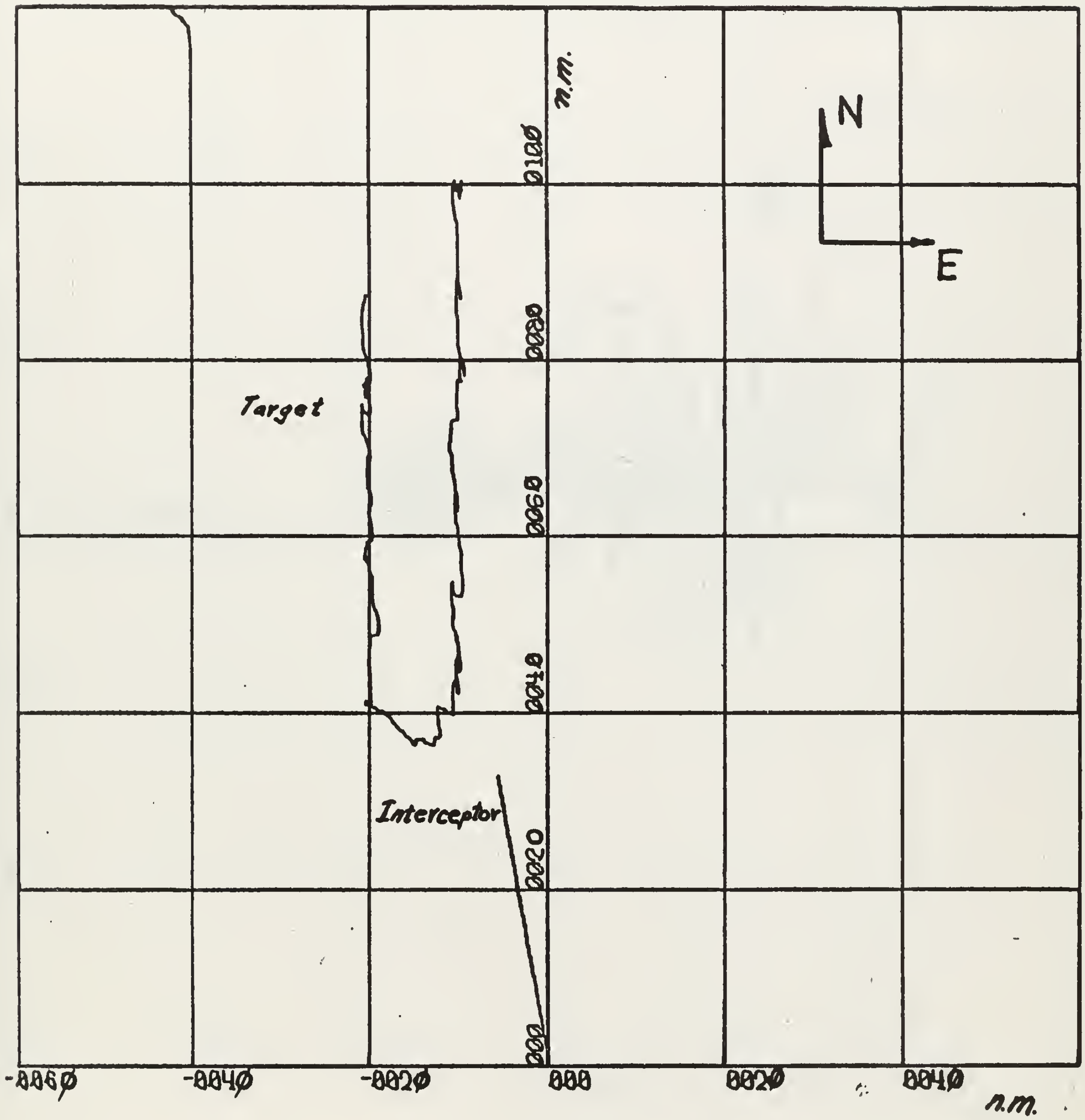
FIGURE 8



X-SCALE = 2.00E+01 UNITS/INCH
Y-SCALE = 2.00E+01 UNITS/INCH

GENTZ NE PLANE SMOOTHED POSITION RUN 1A

[redacted]

UNCLASSIFIED

[redacted]

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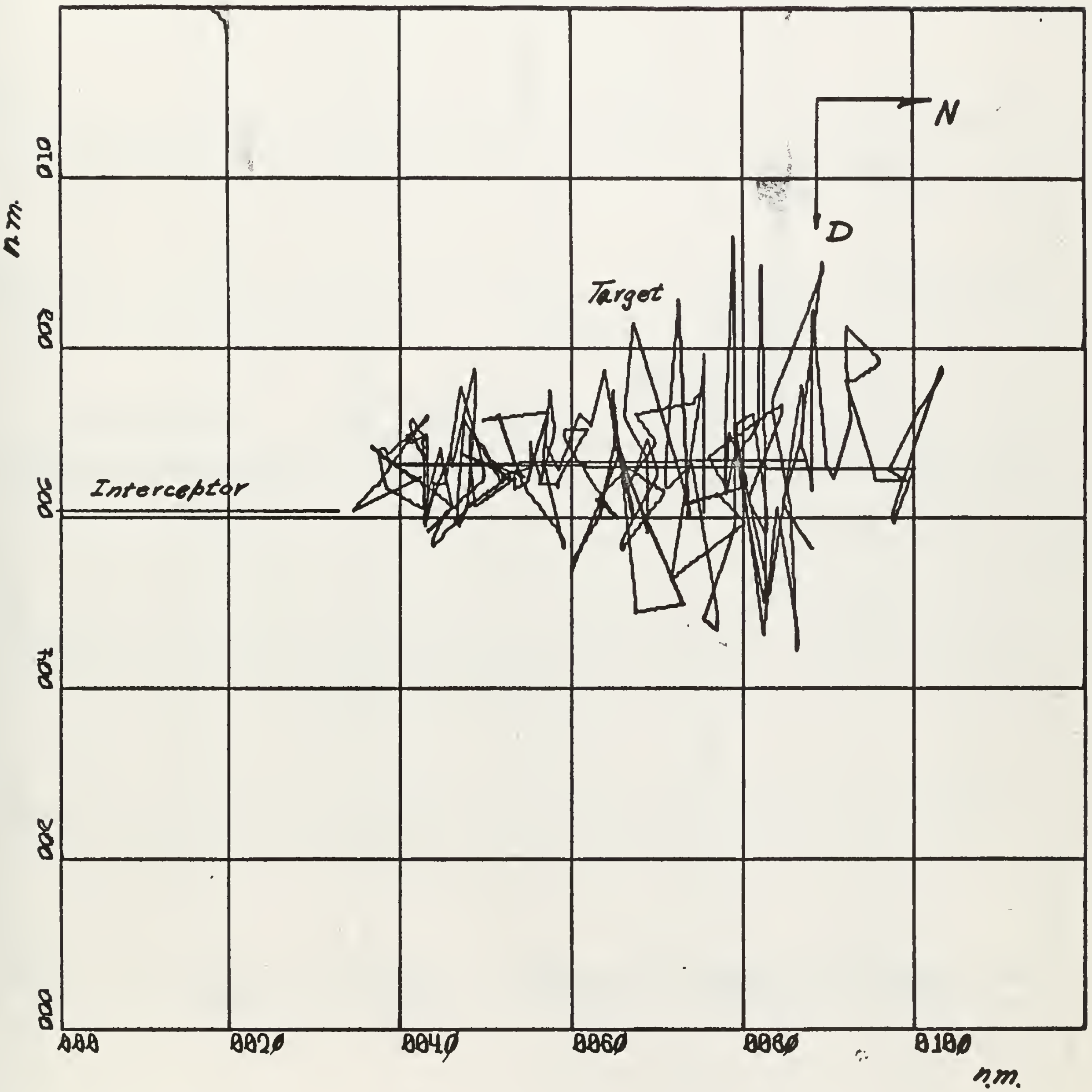
FIGURE 9

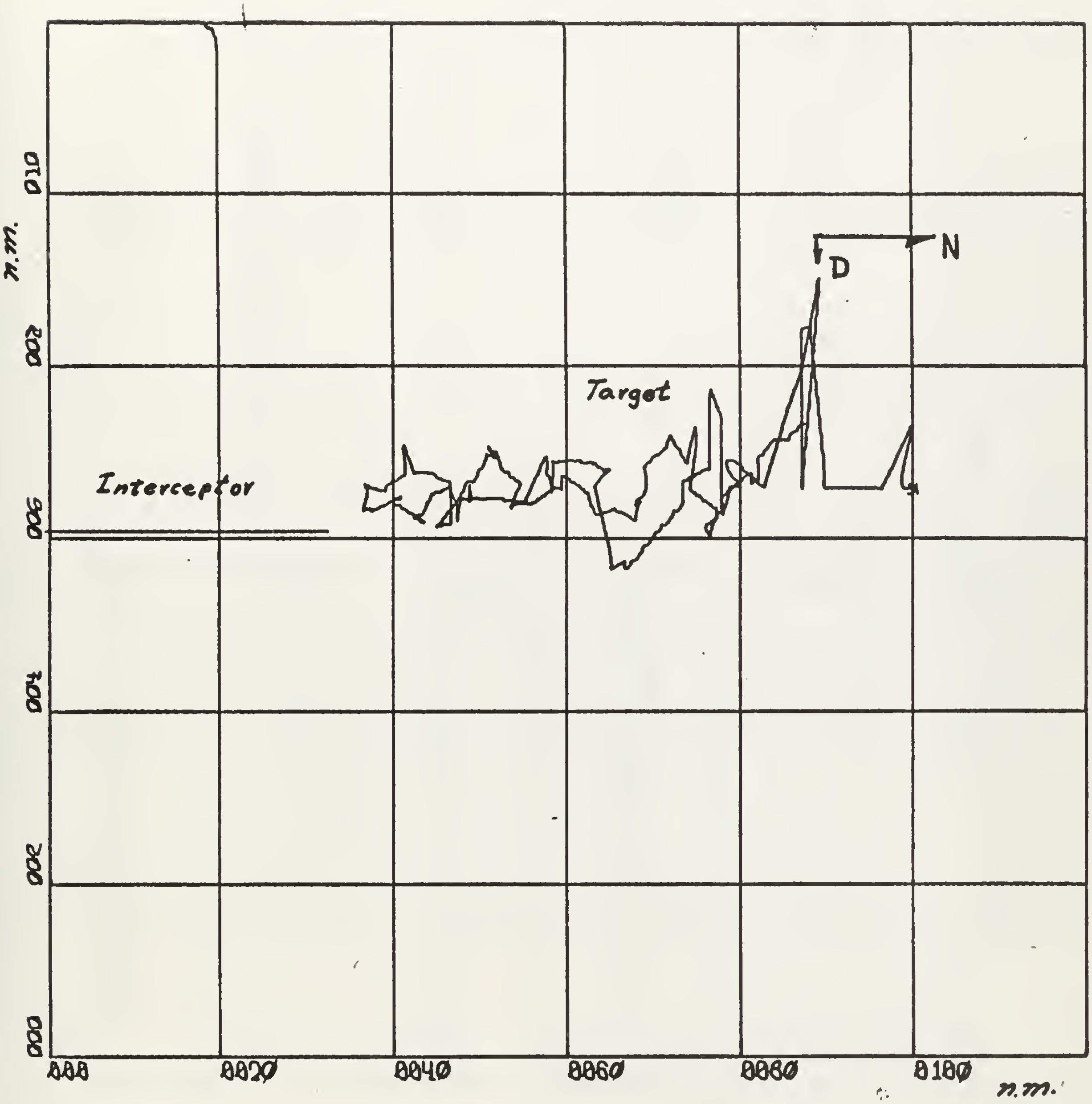


X-SCALE = 2.00E+01 UNITS/INCH
Y-SCALE = 2.00E+00 UNITS/INCH

GENTZ ND PLANE ACTUAL + NOISE RUN 1A

[redacted]

FIGURE 10



X-SCALE = 2.00E+01 UNITS/INCH.
Y-SCALE = 2.00E+00 UNITS/INCH.

CENTZ ND PLANE SMOOTHED POSITION RUN 1A

[redacted]

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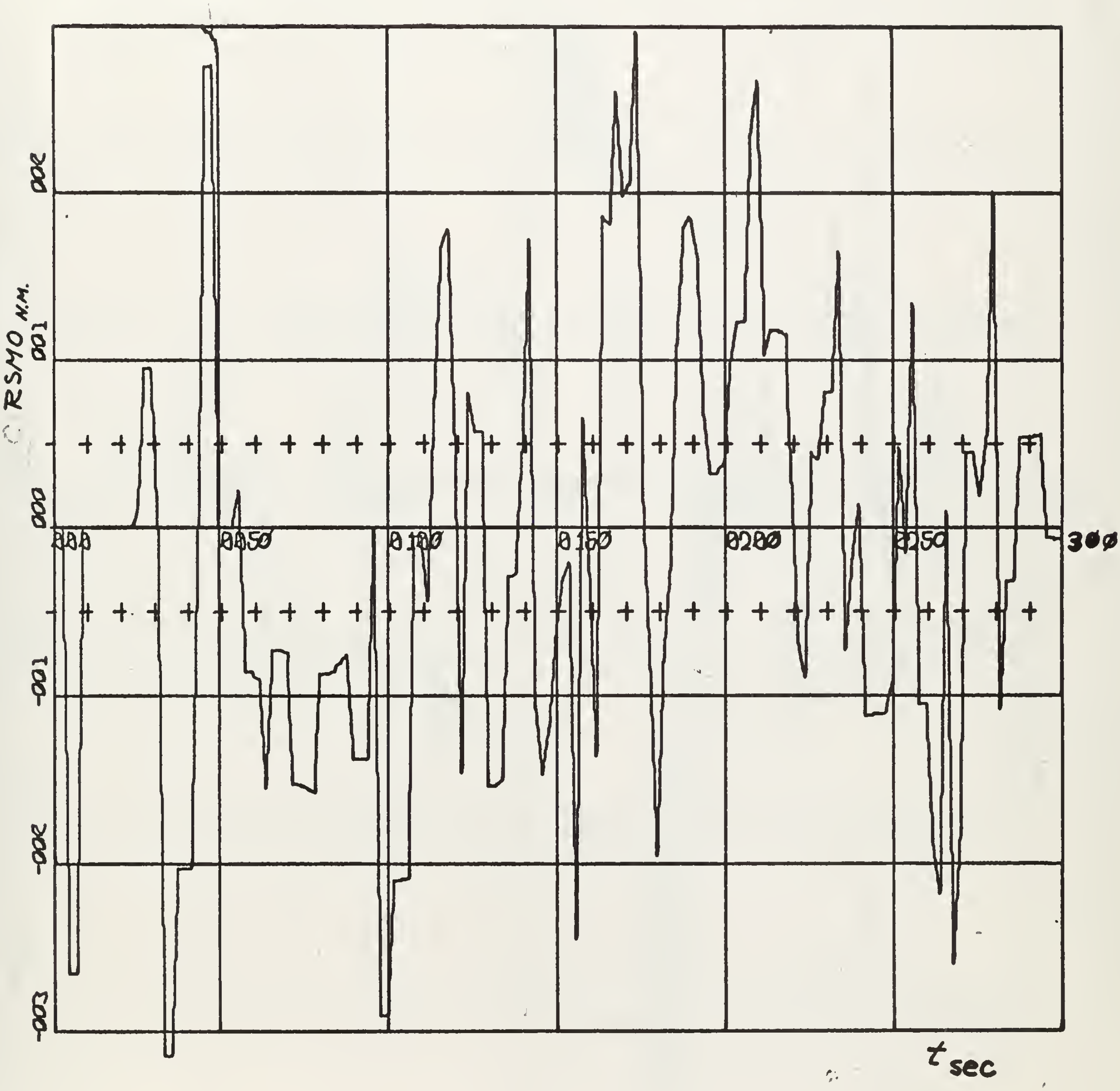
FIGURE 11



X-SCALE = 5.00E+01 UNITS/INCH
Y-SCALE = 1.00E+00 UNITS/INCH

GENTZ RANGE SMOOTHING RESULTS RUN 1A

[redacted]

[redacted]

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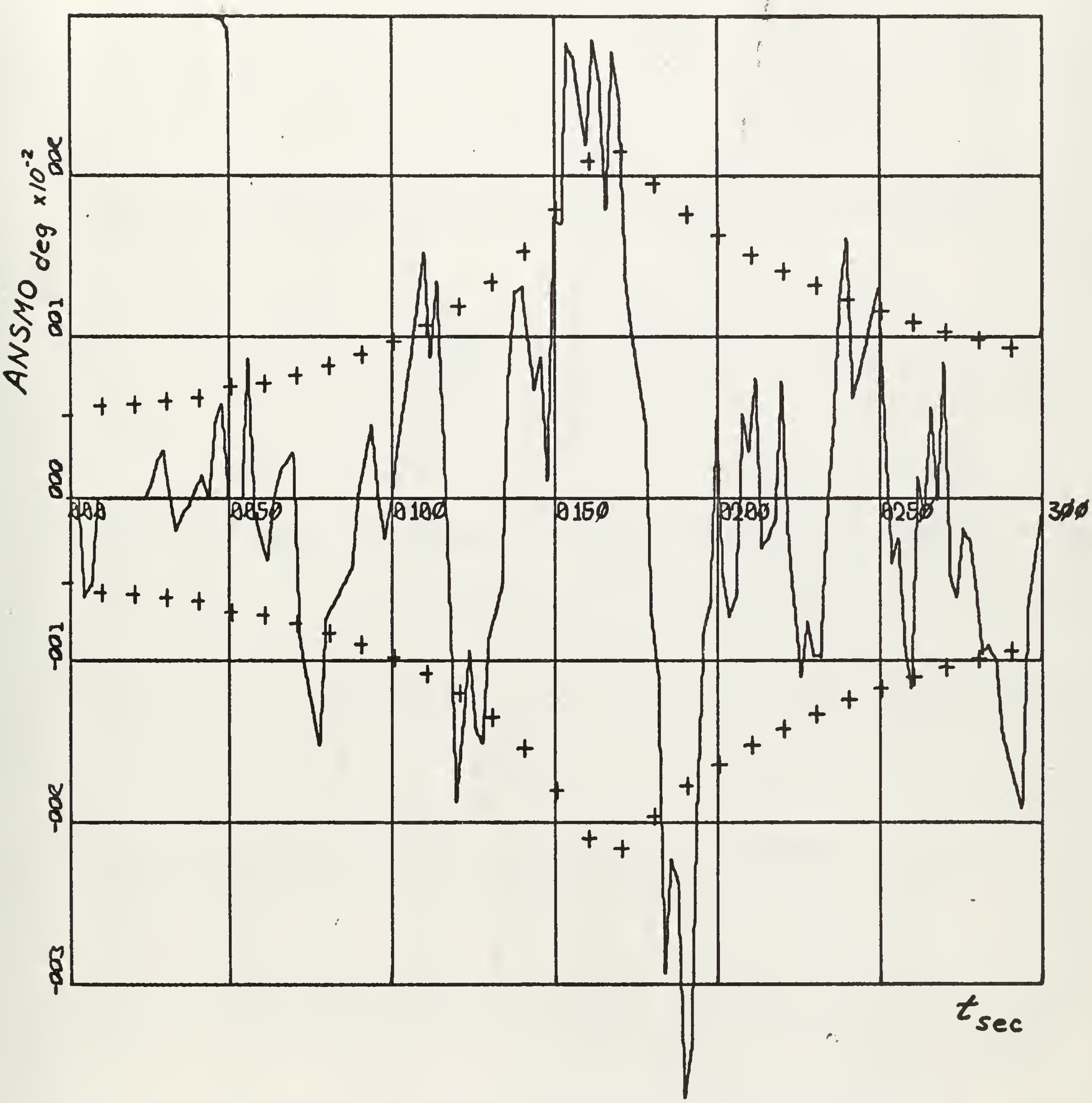
FIGURE 12

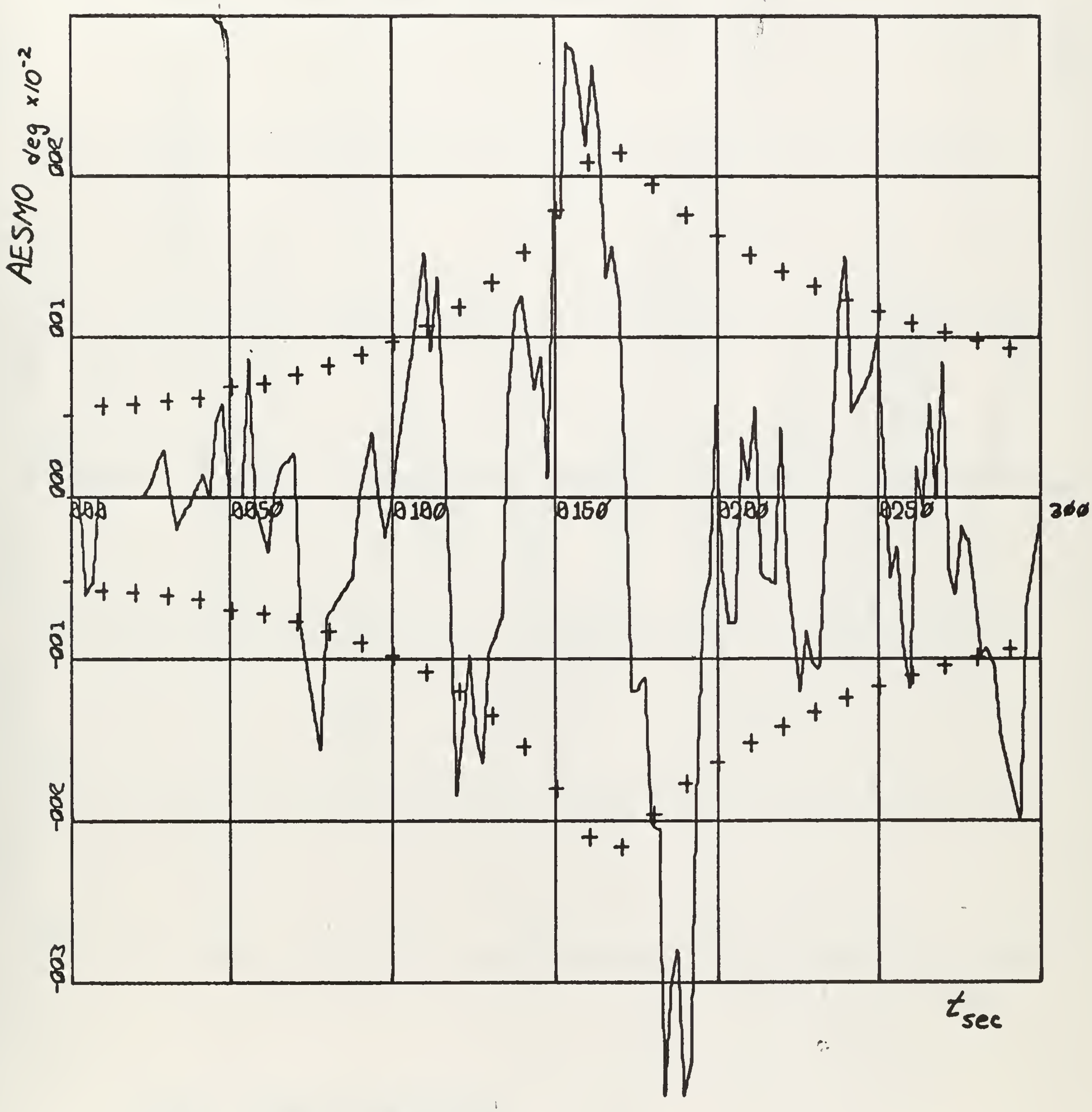


X-SCALE = 5.00E+01 UNITS/INCH.
Y-SCALE = 1.00E-02 UNITS/INCH.

CENTZ NORTH SMOOTHING RESULTS RUN 1A

[redacted]

FIGURE 13

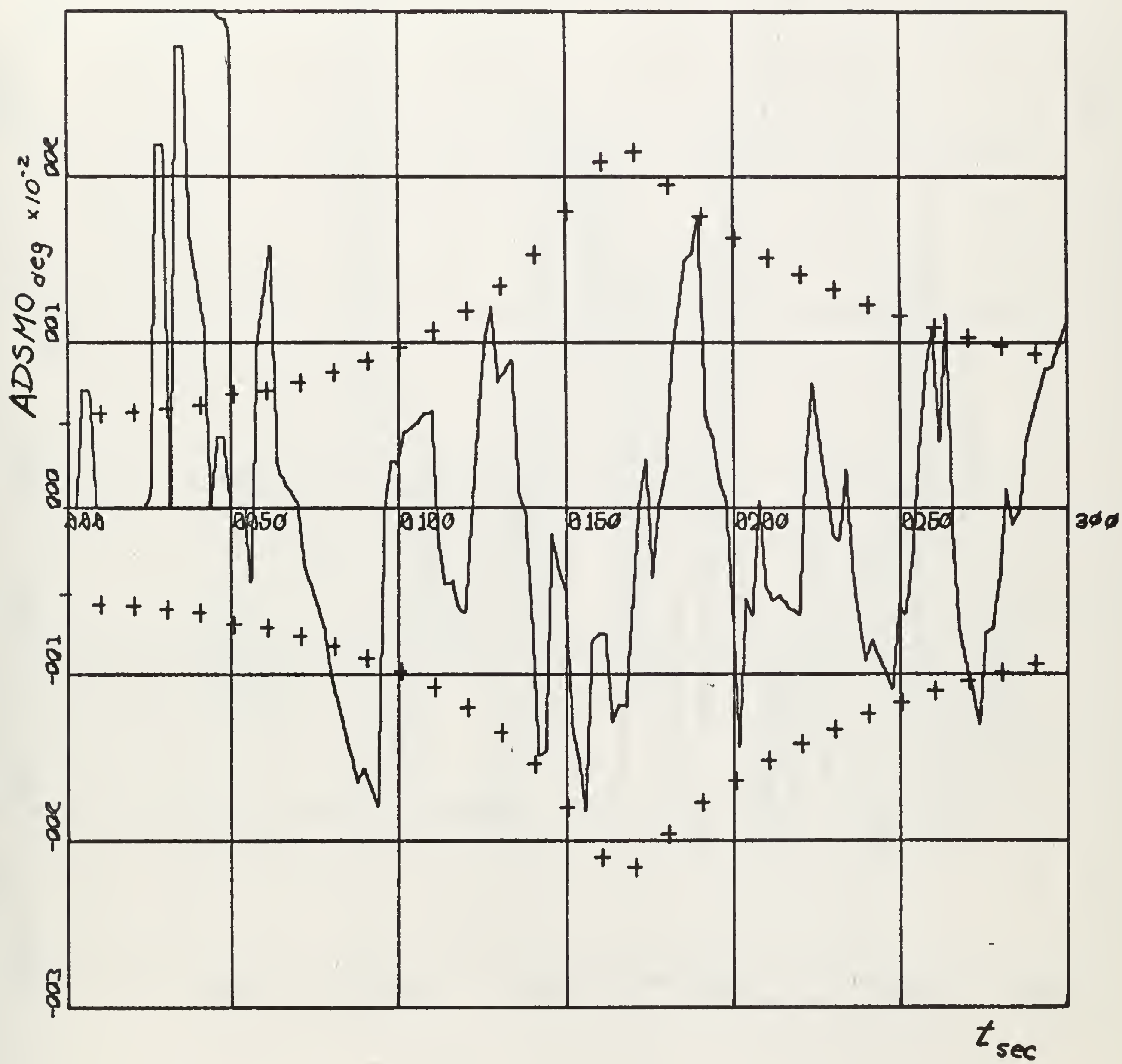


X-SCALE = 5.00E+01 UNITS/INCH.
Y-SCALE = 1.00E-02 UNITS/INCH.

GENTZ EAST SMOOTHING RESULTS RUN 1A

[redacted]

FIGURE 14



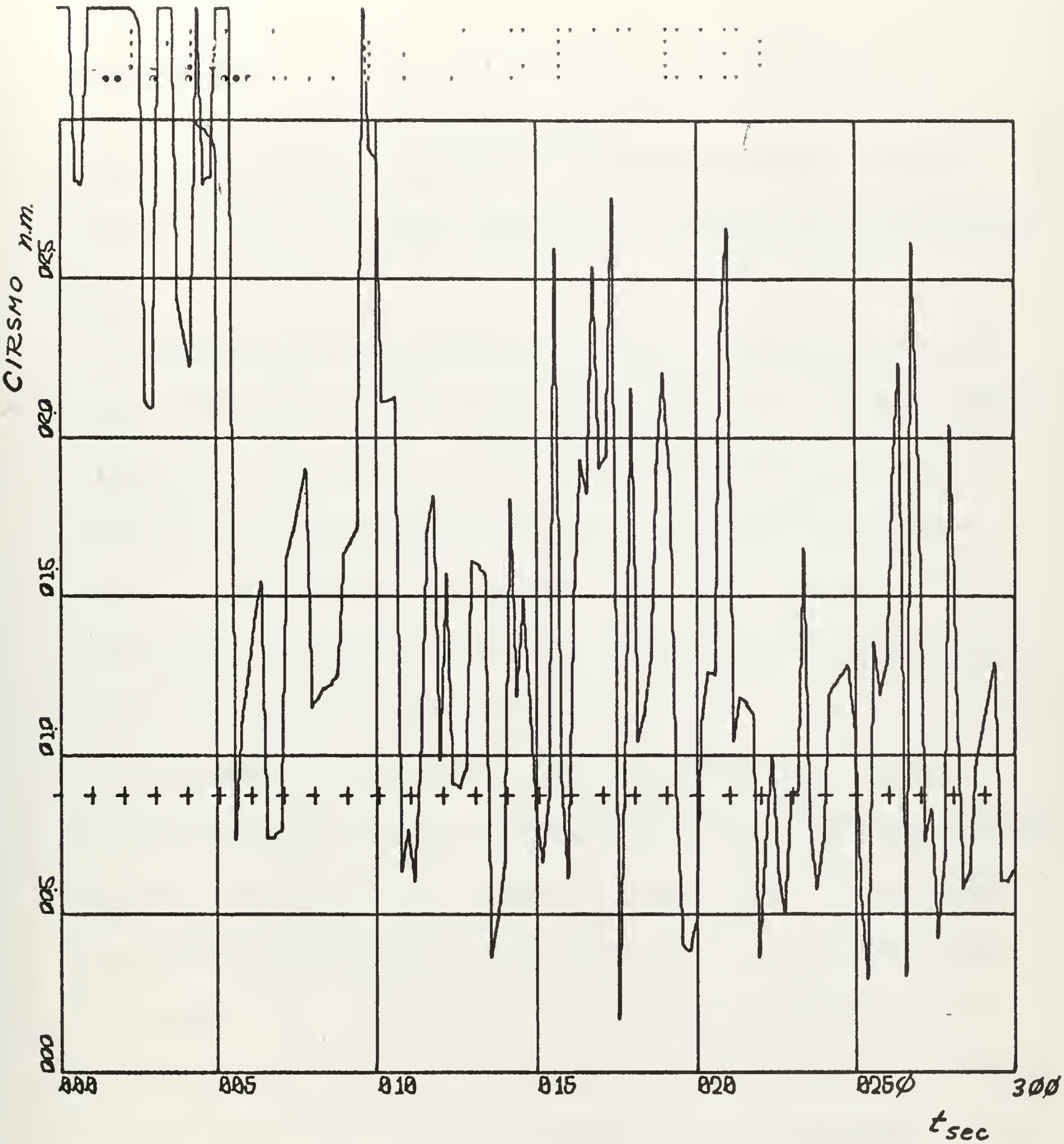
X-SCALE = 5.00E+01 UNITS/INCH.
Y-SCALE = 1.00E-02 UNITS/INCH.

CENTZ DOWN SMOOTHING RESULTS RUN 1A

[redacted]

[redacted]

FIGURE 15



X-SCALE = 5.00E+01 UNITS/INCH.
Y-SCALE = 5.00E-01 UNITS/INCH.

GENTZ 3D RMS SMOOTHING RESULTS RUN 1A

[redacted]

where the rates of change of the direction cosines were high. As was expected the range smoothing results were the prime cause of the smoothed error.

The system was able to smooth the tracks to within one and a half nautical miles inside 50 miles rather consistently, but it tended to respond rather strongly to the noise. It was noted, however, that this had the effect of causing no degradation in performance when the target began maneuvers. Also all the profiles yielded very similar smoothing results indicating that the smoothing constant values used were near optimum for the fixed constant, non-adaptive, system.

In an attempt to more closely define the optimum values of the smoothing constants a program which varied the constants for each smoothed parameter from 0.05 to 1.00 in steps of 0.05 was written. This program is named ALPHA CHECK and listed in Appendix C. The run profiles used were similar to those listed earlier, but, the run time was shortened to 100 seconds so that only the time that the target maneuvered was considered. The average mean square error for the complete run was computed for each smoothed quantity over the range of the values of its smoothing constant. An autocorrelation analysis was also performed to evaluate this noise distribution. The results are shown in Table IV. For these runs the

TABLE IV

AUTOCORRELATION ANALYSIS RESULTS OF PROGRAM
ALPHA CHECK
(51 SAMPLES)

	Mean	Variance	Largest Value of Autocorrelation
RN 1 Target Acceleration Noise	-0.1735	0.6945	0.3947
RN 2 Target Heading Acceleration Noise	0.2439	1.1572	0.2662
RN 3 Target Pitch Acceleration Noise	-0.0986	.9622	0.1774
ATA Antenna Azimuth Noise	0.264	1.2022	-0.2493
EPSI Antenna Elevation Noise	-0.0765	0.8361	0.2544
R Radar Range Noise	0.1438	0.7524	0.2783
RDOT Radar Range Rate Noise	-0.0661	1.1695	0.2805
PD Radar Probability of Detection Noise	-0.0560	0.7587	0.3582

the probability of detection was one. This did not effect the results since no smoothing would have been performed when a contact was missed. The output would have been affected in an indeterminable way, however, by these predicted values.

The results of these runs are shown in Table V. It was apparent from these results that there was considerable interplay between all the variables. Some rationale could be seen in this interaction, but it appeared nonlinear, since any change in the target's profile varied all the points of the optimum values for the smoothing constants. It was noted further that the knuckle in the curves at the optimum point was quite sharp indicating that system performance could be seriously affected when improper values of the smoothing constants were used.

Due to the variations which were found in the optimum values of the smoothing constants for the chosen profiles it was not believed to be necessary to vary the parameters more widely since it was apparent from these runs that the system was very sensitive to changes in the profiles or the values of the system noise.

The question must then be asked as to whether the requirements established for the analysis were too strict. In this regard specifically

TABLE V

OPTIMUM SMOOTHING CONSTANT VALUES
FOR
EACH TEST RUN

Run	Range	Direction Cosines		
		North	East	Down
1 A	0.1	0.25	0.25	0.35
1 B	0.05	0.25	0.25	0.05
1 C	0.15	0.35	0.35	0.05
2 A	0.25	0.90	0.85	0.65
2 B	0.05	0.65	0.55	0.10
2 C	0.35	0.95	0.95	0.40
3 A	0.50	0.60	0.65	0.55
3 B	0.45	0.70	0.55	0.05
3 C	0.55	0.75	0.80	0.05

the standard deviation of range noise and the 0.5 mile value chosen for the desired smoothing error become suspect since they were somewhat arbitrarily chosen. In rebuttal it is strongly felt, in the light of the high overall performance required of the entire system, its cost, and purpose, that the use of this relatively uncontrollable method of smoothing could be disastrous. Since the output of the smoothing section has considerable control over the performance of the system, specifically the accurate positioning of the missile, it is believed that a more adaptive system is desirable. It is further felt that a programmed logic system which would provide for varying the values of the constants would not be warranted since more sophisticated, and proven adaptive systems are available. Possible choices for such a method could be either the Least Squares, or Kalman filter methods.

In short it must be concluded that the α, β, γ Tracker system does not have the response or versatility required for a high performance air to air intercept problem.

[redacted]

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APPENDIX A

TABLE OF SYMBOLS USED IN COMPUTER PROGRAMS

NOTE: If a symbol is used only in the ALPHA CHECK program it is so noted in parenthesis.

ADEV: Absolute value of deviation obtained from RNDEV. This is used in the probability of detection computations.

ADSMO:
AESMO:
ANSMO: Down, east, and north direction cosine differences from actual, and converted to radians.

AD:
AE:
AN:
AR: (ALPHA CHECK) Values of alphas for down, east, and north direction cosines, and for range, used for determining the optimum values.

AERRM:
AERRP: Negative and positive desired limits on ADSMO, AESMO, and ANSMO, a function of actual range.

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ALPHAD: Position smoothing constants for down, east and north
ALPHAE: direction cosines, and for range.
ALPHAN:
ALPHAR:

ANOISE: (ALPHA CHECK) Relative amount of radar parameter noise used in problem.

AT: Target heading and turn rate used in computation of target's
ATDOT: position.

ATA: Antenna's actual and noisy azimuth angle measured positive
ATAE: clockwise, in radians and degrees.
ATAD:
ATADE:

BETAD: Rate smoothing constants for down, east, and north
BETAE: direction cosines.
BETAN:

BT: Target's pitch angle and pitch angle rate used in computation
BTDOT: of target's position.

CIRERR: Three dimensional RMS actual and smoothed error difference
CIRSMO: from actual target position.

DEV: Random deviation obtained from random number generator.

DT: Target position computation step size.

DIRN: North direction cosine actual, noisy, smoothed and
DIRNE: predicted.
DIRNS:
DIRNP:

DIRE: East direction cosine actual, noisy, smoothed and
DIREE: predicted.
DIRES:
DIREP:

DIRD: Down direction cosine actual, noisy, smoothed and
DIRDE: predicted.
DIRDS:
DIRDP:

DIRND: North direction cosine, rate and acceleration.

DIRNDD:

DIRED: East direction cosine, rate and acceleration.

DIREDD:

DIRDD: Down direction cosine, rate and acceleration.

DIRDD:

DDSMO: (ALPHA CHECK) Down east and north direction cosine

DESMO: smoothing differences from actual.

DNSMO:

DELTAT: Target decceleration time to final velocity at -1.75 g.

DIVE: Target maximum dive angle, radians, corresponds to 60 deg.

EPSID: Antenna actual and noisy elevation angle measured positive

EPSIDE: downward, in radians and degrees.

EPSI:

EPSIE:

ERAD: (ALPHA CHECK) Average mean square smoothed error for
ERAE: down, east, and north direction cosines, and for range.
ERAN: They are the quality indicators used for obtaining the
ERAR: optimum values of the smoothing constants.

F: A counter which fixes the target's pull out velocity.

FPOINTS: (ALPHA CHECK) Number of radar returns received.

GAMMAD: Acceleration smoothing constants for the down, east,
GAMMAE: and north direction cosines.
GAMMAN:

GDN*: Target maneuver load factors for push over, pull out,
GDP:* and turn. Note: GDN is a negative number.
GT:*

IT: Hollerith characters which identify the output plots.

I: Number of frame times since problem start.

K: Number of desired limits points plotted from problem start.

* Read into the program

NALPH: (ALPHA CHECK) Number of values of smoothing constants used in finding optimum value.

ND: A zero or one depending on whether detection was missed or not.

NERMAX: Number of points plotted indicating the desired limits on the smoothed errors.

NGRAF1:* Setting NGRAFS to zero supresses various portions of the graph output.
NGRAF2:*
NGRAF3:*

NOISE:* Number of times RNDEV is stepped prior to problem start to allow a different sequence of random numbers to be called.

NPRINT: Number which separates pages of print out.

NQ: Quality counter.

NQC: Counter which reinitializes the initial conditions after the quality counter goes to zero.

* Read into the program

NUMPTS: Number of curve points plotted.

NUNIF: Counter in random number generator.

OM:* Interceptor Mach number.

PD: Target detection probability for each frame time, a function of the actual range.

PI: 3.14159265.

POVERD: Target pushover rate, rad/sec.

POUTD: Target pull out rate, rad/sec.

PSIO:
PSIOD:* Interceptor heading in radians and degrees.

PSIT: Target heading.

PSITD:*
PSITO: Target initial heading, deg. and rad. Note a zero not an alphebetic o on target's initial positions.

Q: Number of frame times since last radar return of range rate.

* Read into the program

R:	Actual and noisy range to target, ft and n.m.
RE:	
RNM:	
RNME:	
RERRM:	Negative and positive desired limits on range, a
RERRP:	constant .5 n.m.
RDOT:	Actual and noisy range rate of target with respect to
RDOTE:	interceptor, positive opening, ft/sec.
RDOTM:	Range rate actual, noisy, predicted, and smoothed,
RDOTME:	n.m./sec.
RDOTMP:	
RDOTMS:	
RDDOTE:	Target noisy acceleration, n.m./sec^2.
RN1:	Random accelerations of target for velocity, heading,
RN2:	and pitch.
RN3:	

RNMP: Predicted and smoothed range to target, n.m.

RNMS:

RSMO: Smoothed range error from actual, n.m.

T: Time since problem start.

TA: Total target iteration time since problem start.

TC: Iteration time which determines time for plotting desired limit points.

TD:* Time to target dive.

TM:* Target Mach number.

TS: Check time against iteration time to enter main program from target iteration.

TT:* Time to target turn.

VO: Intercepter velocity, ft/sec.

VT: Target velocity and acceleration, ft/sec. and ft/sec^2.

VTDOT:

VTF: Final target velocity, a function of the target's final altitude.

* Read into the program

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X1: Points which mark initial target location on the smoothed
X2: plot.

XO: Interceptor position along the north axis, ft. and n.m.
XONM:

XTERR: Difference between target's noisy and smoothed position, n.m.

XTO:* Target position along north axis, initial, actual, and noisy
XT: in feet, and initial, noisy, and smoothed position, n.m.
XTE:
XTONM:
XTNME:
XTNMS:

XTSMO: Target's difference between actual and smoothed x position.

Y1: Similar to X1 and X2.
Y2:

* Read into the program

YTERR: Similar to XTERR.

YTO:* Target's position along the east axis, similar to X positions.

YT:

YTE:

YTONM:

YTNME:

YTNMS:

YTSMO: Target's difference between actual Y position and smoothed Y position.

Z1: Similar to X1 and X2.

Z2:

ZETA: Target's deflection angle from the horizontal, measured positive downward from the Intercepter, rad.

ZO:* Interceptor's altitude, ft. and n.m.

ZONM:

ZTERR: Similar to XTERR.

* Read into the program

[redacted]

ZTO:* Target's altitude similar to X positions.

ZT:

ZTE:

ZTNM:

ZTNME:

ZTNMS:

ZTSMO: Target's difference between actual Z position and smoothed Z position.

ZTF:* Final target altitude, ft.

ZTPO: Target pull out altitude, ft.

* Read into the program

APPENDIX B

COMPUTER PROGRAM DETAILS

A. Purpose: The program is designed to generate three dimensional target-interceptor geometries for use in analyzing optimum smoothing schemes.

B. Limitations: The interceptor starts at the coordinate axis origin and may have any northerly heading. The target may be placed anywhere in the northern semi-circle with any initial heading. The positive axis directions are: X, north, Y, east, and Z, down, measured from the interceptor's altitude. The problem will stop anytime the target flies out of a 65 deg. cone from the interceptor's heading.

C. Program Capabilities: The program will compute the actual range, range-rate, antenna azimuth and elevation for a radar frame time of two seconds. It will put noise on the above having the standard deviations of 2.5 n.m. for range, 8.72kts for range-rate, 0.745 deg. for azimuth, and 0.86 deg. for elevation. It also puts a half g acceleration noise on the target. It will compute the noisy target location, based on the

noise. It will further transfer the actual and noisy radar parameters into a moving north, east, down coordinate system which is fixed to move with the interceptor. It will determine whether detection was made or not each frame time, based on a detection probability curve, and perform a quality counter operation which prevents non-detected targets from being smoothed after they are lost for a reasonable number of frames.

D. Input data requirements: Four input cards are required.

1. The first card reads in 16 Hollerith characters which identify the program on the print out and graphs. The format is 2A8.

2. The second card reads in the interceptor's altitude in feet, the target's X and Y coordinates in nautical miles, and altitude in feet, and interceptor and target heading in degrees. The format is 7F6.0.

3. The third card reads in the target and the interceptor's Mach number, the target's maneuver g load capabilities for turn, pull out, and dive, (negative number), and the problem time to target turn and/or dive. The format is 7F6.2.

4. The fourth card reads in a fixed point number that allows a different starting point for the subroutine RNDEV, and three fixed point ones or zeroes which control the graph output. The first, if zero, suppresses

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the profile curves, the second, if zero, suppresses the smoothed difference plots, and the third, if zero, suppresses the three dimensional rms smoothed difference plot. The format is 4I6.

E. Requirements for reprogramming the smoothing section: The entering arguments of the smoothing and prediction section are RNME, DIRNE, DIREE, DIRDE, and NQC. The suggested statement numbers to use are the 600 series or above 2000.

F. Quality indicators: The primary quality indicator is the three dimension rms smoothed error from the actual position. The three dimensional rms noise error is computed for comparison. The desired smoothing error on the individual quantities is 0.5 n.m. This could give a three dimensional rms smoothed error of as much as 0.875 n.m. The output curves have points plotted indicating these limits.

G. Output: The print out contains the run identification read in, the problem time, the three dimensional rms actual and smoothed error, whether detection was made or not, ND equals one or zero, and the status of the quality counter, NQ. There are nine output curves. They plot the following:

1. The interceptor and target's actual and noisy positions in the north-east plane.

2. The interceptor position and the target's smoothed position in the north-east plane.

3. The interceptor and target's actual and noisy positions in the north-down plane.

4. The interceptor's position and the smoothed target's position in the north-down plane.

5. The range smoothed differences from actual and the desired limit points, versus time.

6. The north direction cosine smoothed differences from actual and the desired limits points plotted as a function of actual range, versus time.

7. The east direction cosine smoothed differences similar to the north direction cosine curve.

8. The down direction cosine smoothed differences similar to the north direction cosine curve.

9. The three dimensional rms smoothed error from actual and the desired limits points, versus time.

H. Run time: The average run time is between 2 minutes and 30 seconds and 2 minutes and 50 seconds.

```
      PROGRAM THREE D
C     THIS PROGRAM COMPUTES THREE DIMENSIONAL INTERCEPTER-TARGET
C     GEOMETRIES FOR THE PURPOSE OF OPTIMIZING VAROUS PARAMETERS.
C     THE PROGRAM WILL STOP ANY TIME THAT THE TARGET FLIES OUTSIDE OF A
C     65 DEGREE CONE FROM THE INTERCEPTERS HEADING.
C     FOUR INPUT CARDS ARE REQUIRED
C     1.  THE FIRST CARD READS IN 16 HOLLERITH CHARACTERS WHICH IDENT-
C     IFY THE PROGRAM ON THE PRINT OUT AND GRAPHS.  THE FORMAT IS 2A8.
C     2.  THE SECOND CARD READS IN INTERCEPTERS ALTITUDE IN FEET,
C     TARGETS X AND Y COORDINATES IN NAUTICAL MILES AND Z COORDINATE
C     IN FEET, AND INTERCEPTER AND TARGET HEADING IN DEGREES.  THE
C     FORMAT IS 7F6.0.
C     3. THE THIRD CARD READS IN TARGET INTERCEPTER MACH NUMBER,
C     TARGET MANEUVER G LOAD CAPABILITIES FOR TURN PULL OUT AND DIVE
C     (NEGATIVE NUMBER), AND THE PROBLEM TIME TO TARGET TURN AND DIVE.
C     THE FORMAT IS 7F6.2.
C     4.  THE FOURTH CARD READS IN A FIXED POINT NUMBER THAT ALLOWS
C     A DIFFERENT STARTING POINT FOR THE SUBROUTINE RNDEV, AND THREE
C     FIXED POINT ONES OR ZEROS WHICH CONTROL THE GRAPH OUTPUT.  THE
C     FIRST IF ZERO SUPPRESSES THE PROFILE CURVES, THE SECOND IF ZERO
C     SUPPRESSES THE SMOOTHED DIFFERENCE PLOTS, AND THE THIRD IF ZERO
C     SUPPRESSES THE 3D RMS SMOOTHED ERROR PLOT.  THE FORMAT IS 4I6.

C                       DIMENSION AND READ STATEMENTS

      DIMENSION T(151),XONM(151),YONM(151),ZONM(151),XTNM(151),YTNM(151)
     1,ZTNM(151),RNM(151),ATAD(151),RNME(151),RDOTME(151),ATADE(151),
     2RNMS(151),RDOTM(151),XTNME(151),YTNME(151),ZTNME(151),XTNMS(151),
     3YTNMS(151),ZTNMS(151),     IT(12),DIRN(151),DIRE(151),DIRD(151),
     4DIRNE(151),DIREE(151),DIRDE(151),RDDOTE(151),RNMP(151),RDOTMP(151)
     5,DIRNS(151),DIRES(151),DIRDS(151),DIRND(151),DIRED(151),DIRDD(151)
     6,DIRNDD(151),DIREDD(151),DIRDDD(151),DIRNP(151),DIREP(151),DIRDP
     7(151),EPSID(151),EPSIDE(151),RSMO(151),ANSMO(151),AESMO(151),ADSMO
     8(151),ZETA(151),NQ(151),XTSMO(151),YTSMO(151),ZTSMO(151),CIRERR(15
     91),AERRP(30),AERRM(30),RERRP(30),RERRM(30),TC(30),RERR(151)
      DIMENSION X1(2),Y1(2),Z1(2),X2(2),Y2(2),Z2(2),CERRP(30)
     1,XTERR(151),YTERR(151),ZTERR(151),CIRSMO(151),ND(151)
      DO 2 J=1,6
      READ 100(IT(I),I=5,6)
  100 FORMAT(2A8)
      READ 11,ZO,XTONM,YTONM,ZTO,ZTF,PSIOD,PSITD,TM,OM,GT,GDP,GDN,
     1TT,TD,NOISE,NGRAF1,NGRAF2,NGRAF3
   11 FORMAT(7F6.0,/,7F6.2,/,4I6)

C                        INITIAL CONDITIONS

  300 T(1)=0.
      TC(1)=0.
      TA=0.
      TS=0.
      NERMAX=30
      PI=3.14159265
      RAD=180./PI
      DIVE=-60./RAD
      DT=.05
      NUMPTS=151
      NPRINT=68
```

[redacted]


```
      NQC=1
      NQ(1)=0
      NQ(0)=0
      NCTC=0
      F=1.
      Q=1.
      K=1
      XTO=XTONM*6076.1
      YTO=YTONM*6076.1
      XT=XTO
      YT=YTO
      ZT=ZTO
      PSIT0=PSITD/RAD
      PSIO=PSIOD/RAD
      PSIT=PSIT0
      AT=PSIT0
      ATDOT=0.
      ATDDOT=0.
      BT=0.
      BTDOT=0.
      BTDDOT=0.
      RN1=0.
      RN2=0.
      RN3=0.
      NUNIF=1220703125
C           TARGET AND INTERCEPTER VELOCITY COMPUTATIONS
      VTDOT=0.
      IF(ZTO-37000.)63,69,69
   63 VT=TM*(1116.-.00398*ZTO)
      GO TO 57
   69 VT=TM*967.6
   57 IF(ZO-37000.)73,74,74
   73 VO=OM*(1116.-.00398*ZO)
       GO TO 75
   74 VO=OM*967.6
   75 IF(ZTF-10000.)78,79,79
   78 VTF=1340.+0.08*ZTF
      DELTAT=(VT-VTF)/56.4
      GO TO 58
   79 VTF=VT
      DELTAT=0.
   58 CONTINUE
C           THIS ALLOWS A VARIATION IN THE RANDOM NUMBER SEQUENCE
      IF(NOISE)109,109,122
  122 DO 102 L=1,NOISE
  102 CALL RNDEV(NUNIF,DEV)
  109 CONTINUE
C                            BEGIN MAIN PROGRAM DO LOOP
      DO 20 I=1,151
C           CHECK ITERATION TIME AGAINST RADAR FRAME TIME
   22 IF(ABSF(TS-TA)-10.E-5)25,25,24
C           CHECK MANEUVER TIMES AND/OR READ IN MANEUVER CONDITIONS
```

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```
   24 TA=TA+DT
      IF(TA-TT)39,28,28
   39 ATDOT=0.
      GO TO 29
   28 ATDOT=GT*32.17/VT
   29 IF(TA-TD)40,41,41
   40 BTDOT=0.
      GO TO 42
   41 IF(ZT-ZTF)76,77,77
   76 BTDOT=(GDP-1.)*32.17/VT
      GO TO 42
   77 BTDOT=(GDN-1.)*32.17/VT
      VTDOT=-56.4
   42 IF((PSIT0+PI)-AT)46,46,45
   46 ATDOT=0.
      AT=PSIT0+PI
   45 IF(BT-DIVE)34,34,35
   34 BTDOT=0.
      BT=DIVE
   35 IF (F) 201,201,203
  203 ZTPO=(1.-COSF(BT))*VT**2/((GDP-1.)*32.17)+ZTF
      IF (ZTPO-ZT)38,37,37
   37 IF(F)201,201,200
  200 F=F-1.
      VTPO=VT
  201 BTDOT=(GDP-1.)*32.17/VTPO
      IF(BT)38,43,43
   43 BTDOT=0.
      BT=0.

   38 IF(ZT-ZTF)205,205,206
  205 ZT=ZTF
  206 IF(TA-(TD+DELTAT))51,51,202
  202 VTDOT=0.
      VT=VTF

C           ITERATION OF TARGETS POSITION

   51 VT=VT+VTDOT*DT+RN1*DT
      AT=AT+ATDOT*DT+RN2*DT**2/2.
      PSIT=AT
      BT=BT+BTDOT*DT+RN3*DT**2/2.

C           COMPUTE TARGET POSITION

      XT=XT+VT*COSF(BT)*COSF(AT)*DT
      YT=YT+VT*COSF(BT)*SINF(AT)*DT
      ZT=ZT+VT*SINF(BT)*DT

C           RETURN TO START TO CHECK AGAINST RADAR LOOK TIME

       GO TO 22
   25 TS=TS+2.

C     COMPUTE INTERCEPTERS POSITION AND ACTUAL RADAR PARAMETERS

      XO=VO*T(I)*COSF(PSIO)
      YO=VO*T(I)*SINF(PSIO)
      R=SQRTF((XT-XO)**2+(YT-YO)**2+(ZT-ZO)**2)
      EPSI=ASINF((ZO-ZT)/R)
      IF(PSIO-PI)60,59,59
   59 PSIO=PSIO-2.*PI
```

[redacted]

```
 60 IF(YT-YO)31,32,32
 31 ATA=-ACOSF((XT-XO)/(R*COSF(EPSI)))-PSIO
    GO TO 33
 32 ATA=ACOSF((XT-XO)/(R*COSF(EPSI)))-PSIO
C           CHECK IF TARGET IS STILL IN RADAR BEAM, IF NOT STOP
 33 IF(ATA-1.1345)26,26,50
 26 IF(ATA+1.1345)50,49,49
 49 IF(EPSI-1.1345)48,48,50
 48 IF(EPSI+1.1345)50,27,27
 50 NUMPTS=(I-1)
    NERMAX=NUMPTS/10
    NPLOT=NUMPTS-NCTC
    IF(NUMPTS-68)15,14,14
 15 NPRINT=NUMPTS
 14 GO TO 1
 27 RDOT=-VT*COSF(PSIT-ACOSF((XT-XO)/(R*COSF(EPSI)))+PI)*COSF(EPSI)
   1-VO*COSF(ATA)*COSF(EPSI)
C           CONVERT ACTUAL RADAR PARAMETERS TO KTS, NM/SEC, DEG
    RNM(I)=R/6076.1
    ATAD(I)=ATA*RAD
    EPSID(I)=EPSI*RAD
    RDOTM(I)=RDOT/6076.1
    XONM(I)=XO/6076.1
    YONM(I)=YO/6076.1
    ZONM(I)=ZO/6076.1
    XTNM(I)=XT/6076.1
    YTNM(I)=YT/6076.1
    ZTNM(I)=ZT/6076.1
C           OBTAIN TARGET MANEUVER NOISE
    CALL RNDEV(NUNIF,DEV)
    RN1=16.*DEV
    CALL RNDEV(NUNIF,DEV)
    RN2=16./VT*DEV
    CALL RNDEV(NUNIF,DEV)
    RN3=16./VT*DEV
C           OBTAIN NOISY RADAR PARAMETERS AND CONVERT TO CONVENIENT UNITS
    CALL RNDEV(NUNIF,DEV)
    ATAE=ATA+.013*DEV
    CALL RNDEV(NUNIF,DEV)
    RE=R+15000.*DEV
    CALL RNDEV(NUNIF,DEV)
    EPSIE=EPSI+.015*DEV
    CALL RNDEV(NUNIF,DEV)
    RDOTE=RDOT+14.7174*DEV
    ATADE(I)=ATAE*RAD
    EPSIDE(I)=EPSIE*RAD
    RNME(I)=RE/6076.1
    RDOTME(I)=RDOTE/6076.1
C           COMPUTE NOISY TARGET SPACE STABILIZED POSITION
    IF(PSIO-1.)70,70,71
 70 XTE=XO+RE*COSF(ATAE+PSIO)*COSF(EPSIE)
    YTE=YO+RE*SINF(ATAE+PSIO)*COSF(EPSIE)
```

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```
      GO TO 72
   71 XTE=XO+RE*COSF(ATAE-PSIO)*COSF(EPSIE)
      YTE=YO+RE*SINF(ATAE-PSIO)*COSF(EPSIE)
   72 ZTE=ZO-RE*SINF(EPSIE)
      XTNME(I)=XTE/6076.1
      YTNME(I)=YTE/6076.1
      ZTNME(I)=ZTE/6076.1

C          COMPUTE ACTUAL DIRECTION COSINES FOR INTERCEPTER WITH ROLL
C          AND PITCH ZERO

      DIRN(I)=COSF(ATA)*COSF(PSIO)-SINF(ATA)*SINF(PSIO)
      DIRE(I)=COSF(ATA)*SINF(PSIO)+SINF(ATA)*COSF(PSIO)
      DIRD(I)=-SINF(EPSI)

C          COMPUTE NOISY DIRECTION COSINES

      DIRNE(I)=COSF(ATAE)*COSF(PSIO)-SINF(ATAE)*SINF(PSIO)
      DIREE(I)=COSF(ATAE)*SINF(PSIO)+SINF(ATAE)*COSF(PSIO)
      DIRDE(I)=-SINF(EPSIE)

C          OBTAIN DETECTION PROBABILITY AND DETERMINE IF TARGET WAS
C          DETECTED

      CALL RNDEV (NUNIF,DEV)
      IF(RNM(I)-20.)21,23,23
   21 PD=2.36-.043*RNM(I)
      GOTO 52
   23 IF (RNM(I)-50.)36,47,47
   36 PD=1.95-.0239*RNM(I)
      GO TO 52
   47 IF (RNM(I)-80.)65,66,66
   65 PD=1.55-.016*RNM(I)
      GO TO 52
   66 IF (RNM(I)-110.)62,68,68
   62 PD=.88-.0077*RNM(I)
      GO TO 52
   68 PD=.25-.0019*RNM(I)
   52 CONTINUE
      ADEV=ABSF(DEV)
      IF(PD-ADEV)53,54,54

C          QUALITY COUNTER COMPUTATIONS

   53 ND(I)=0
      NQ(I)=NQ(I-1)-1
      IF (NQ(I))250,151,152
  250 NQ(I)=0
      GO TO 151
   54 ND(I)=1
      NQ(I)=NQ(I-1)+2
      IF (10-NQ(I))251,153,153
  251 NQ(I)=10
      GO TO 153

C               SMOOTHING AND PREDICTION SECTION

C          NO DETECTION CONDITIONS

C          IF QUALITY COUNTER IS ZERO PRINT THE FOLLOWING AND START NEXT
C          FRAME TIME
```

[redacted]

[redacted]

```
151 CIRERR(I)=999.9999
    CIRSMO(I)=999.9999
    XTNMS(I)=XTNM(I)
    YTNMS(I)=YTNM(I)
    ZTNMS(I)=ZTNM(I)
    ND(I)=99
    NQC=1
    GO TO 20

C          IF QUALITY COUNTER IS NON ZERO ERROR VALUES EQUAL PREDICTED
C          ONES, COMPUTE ONLY NEXT PREDICTED VALUES

152 RNME(I)=RNMP(I)
    RDOTME(I)=RDOTMP(I)
    DIRNE(I)=DIRNP(I)
    DIREE(I)=DIREP(I)
    DIRDE(I)=DIRDP(I)
    GO TO 61

C          DETECTION CONDITIONS

153 IF (NQC)61,61,154

C          INITIAL CONTACT CONDITIONS AT START OR AFTER CONTACT HAS
C          BEEN LOST AND REGAINED

154 NQC=NQC-1
    RNMP(I)=RNME(I)
    RDOTMP(I)=RDOTME(I)
    DIRNP(I)=DIRNE(I)
    DIREP(I)=DIREE(I)
    DIRDP(I)=DIRDE(I)
    RDDOTE(I-1)=0.
    DIRND(I-1)=0.
    DIRNDD(I-1)=0.
    DIRED(I-1)=0.
    DIREDD(I-1)=0.
    DIRDD(I-1)=0.
    DIRDDD(I-1)=0.
 61 CONTINUE

C          SMOOTHING CONSTANT COMPUTATIONS

    ALPHAR=.45
    ALPHAN=.43
    BETAN=ALPHAN**2/(2.-ALPHAN)
    GAMMAN=2.*BETAN/ALPHAN-(ALPHAN+BETAN )
    ALPHAE=ALPHAN
    ALPHAD=.35
    BETAD=ALPHAD**2/(2.-ALPHAD)
    GAMMAD=2.*BETAD/ALPHAD-(ALPHAD+BETAD )

C          SMOOTHING AND PREDICTION COMPUTATIONS

C          RANGE

    RNMS(I)=RNMP(I)+ALPHAR*(RNME(I)-RNMP(I))
    RDDOTE(I)=RDDOTE(I-1)+1./(2.*Q)*(RDOTME(I)-RDOTMP(I))
    RNMP(I+1)=RNMS(I)+2.*RDOTME(I)+2.*RDDOTE(I)
    RDOTMP(I+1)=RDOTME(I)+2.*RDDOTE(I)

C          NORTH DIRECTION COSINE
```

[redacted]

```
      DIRNS(I)=DIRNP(I)+ALPHAN*(DIRNE(I)-DIRNP(I))
      DIRND(I)=DIRND(I-1)+2.*DIRNDD(I-1)+BETAN/2.*(DIRNE(I)-DIRNP(I))
      DIRNDD(I)=DIRNDD(I-1)+2.*GAMMAN/4.*(DIRNE(I)-DIRNP(I))
      DIRNP(I+1)=DIRNS(I)+2.*DIRND(I)+2.*DIRNDD(I)

C           EAST DIRECTION COSINE

      DIRES(I)=DIREP(I)+ALPHAN*(DIREE(I)-DIREP(I))
      DIRED(I)=DIRED(I-1)+2.*DIREDD(I-1)+BETAN/2.*(DIREE(I)-DIREP(I))
      DIREDD(I)=DIREDD(I-1)+2.*GAMMAN/4.*(DIREE(I)-DIREP(I))
      DIREP(I+1)=DIRES(I)+2.*DIRED(I)+2.*DIREDD(I)

C           DOWN DIRECTION COSINE

      DIRDS(I)=DIRDP(I)+ALPHAD*(DIRDE(I)-DIRDP(I))
      DIRDD(I)=DIRDD(I-1)+2.*DIRDDD(I-1)+BETAD/2.*(DIRDE(I)-DIRDP(I))
      DIRDDD(I)=DIRDDD(I-1)+2.*GAMMAD/4.*(DIRDE(I)-DIRDP(I))
      DIRDP(I+1)=DIRDS(I)+2.*DIRDD(I)+2.*DIRDDD(I)

C           COMPUTE SMOOTHED TARGET POSITION

      ZETA(I)=ACOSF(DIRDS(I))-PI/2.
      XTNMS(I)=XONM(I)+RNMS(I)*COSF(ZETA(I))*DIRNS(I)
      YTNMS(I)=YONM(I)+RNMS(I)*COSF(ZETA(I))*DIRES(I)
      ZTNMS(I)=ZONM(I)+DIRDS(I)*RNMS(I)

C           COMPUTE SMOOTHED AND ERROR DIFFERENCES FROM ACTUAL


      XTSMO(I)=XTNM(I)-XTNMS(I)
      YTSMO(I)=YTNM(I)-YTNMS(I)
      ZTSMO(I)=ZTNM(I)-ZTNMS(I)
      XTERR(I)=XTNM(I)-XTNME(I)
      YTERR(I)=YTNM(I)-YTNME(I)
      ZTERR(I)=ZTNM(I)-ZTNME(I)
      RSMO(I)=RNM(I)-RNMS(I)

C           COMPUTE THE ACTUAL AND SMOOTHED 3D RMS ERROR VALUES

      CIRERR(I)=SQRTF(XTERR(I)**2+YTERR(I)**2+ZTERR(I)**2)
      CIRSMO(I)=SQRTF(XTSMO(I)**2+YTSMO(I)**2+ZTSMO(I)**2)

C           CHECK TO SEE IF THE ACOSF ARGUMENT HAS BEEN EXCEEDED,
C           IF IT HAS SET THE COSINE EQUAL TO ONE AND PRINT OUT THE VALUE

      IF (DIRNS(I)-1.)211,211,210
  210 PRINT 212,(T(I),DIRNS(I))
  212 FORMAT(6X2HT= F8.4,2X6HDIRNS=F8.4)
      DIRNS(I)=1.0
  211 IF(DIRES(I)-1.)221,221,220
  220 PRINT222,(T(I),DIRES(I))
  222 FORMAT(6X2HT=F8.4,2X6HDIRES=F8.4)
      DIRES(I)=1.0
  221 IF(DIRDS(I)-1.0)231,231,230
  230 PRINT232,(T(I),DIRDS(I))
  232 FORMAT(6X2HT=F8.4,2X6HDIRDS=F8.4)
      DIRDS(I)=1.0
  231 CONTINUE

C           CONVERT THE DIRECTION COSINES TO DEGREES FOR GRAPH OUTPUT
```

[redacted]

```
      ANSMO(I)=ACOSF(DIRN(I))-ACOSF(DIRNS(I))
      AESMO(I)=ACOSF(DIRE(I))-ACOSF(DIRES(I))
      ADSMO(I)=ACOSF(DIRD(I))-ACOSF(DIRDS(I))

C           COMPUTE THE DESIRED LIMIT POINTS FOR THE GRAPH OUTPUTS

      IF(TC(K)-T(I))120,120,121
  120 TC(K+1)=TC(K)+10.
      AERRP(K)=ATANF(.5/RNM(I))
      AERRM(K)=-AERRP(K)
      RERRP(K)=.5
      RERRM(K)=-.5
      CERRP(K)=.875
      K=K+1
  121 CONTINUE

C           IF DETECTION WAS MISSED INCREASE Q IN THE RDOT SMOOTHING
C           COMPUTATIONS

      IF (ND(I))55,55,56
   55 Q=Q+1.
      GO TO 20
   56 Q=1.
   20 T(I+1)=T(I)+2.

C           END OF MAIN PROGRAM DO LOOP

    1 CONTINUE

C                                 OUTPUT CONTROL

C           COMPUTE MARKERS WHICH INDICATE THE TARGETS INITIAL POSITION
C           ON THE SMOOTHED PROFILE CURVES

      X1(1)=XTONM+.5
      X1(2)=XTONM-.5
      Y1(1)=YTONM+.5
      Y1(2)=YTONM-.5
      Z1(1)=ZT0/6076.1+.05
      Z1(2)=ZT0/6076.1-.05
      X2(1)=XTONM+.5
      X2(2)=XTONM-.5
      Y2(1)=YTONM-.5
      Y2(2)=YTONM+.5
      Z2(1)=ZT0/6076.1-.05
      Z2(2)=ZT0/6076.1+.05

C           GRAPH STATEMENTS

      IF (NGRAF1)270,270,271
  271 CONTINUE
      DO 101 I=1,4
  101 IT(I)=8H
      IT(1)=8HGENTZ NE
      IT(2)=8H PLANE A
      IT(3)=8HCTUAL +
      IT(4)=8HNOISE
      I=1
      CALL DRAW(NUMPTS,YONM,XONM,1,0,4H    ,IT,15.,15.,0,3,2,2,6,6,1,
     1LAST)
      CALL DRAW(NUMPTS,YTNM,XTNM,2,0,4H    )
      CALL DRAW(NUMPTS,YTNME,XTNME,3,0,4H    )
```

[redacted]

[redacted]

```
      DO 103 I=1,4
  103 IT(I)=8H
      IT(1)=8HGENTZ NE
      IT(2)=8H PLANE S
      IT(3)=8HMOOTHED
      IT(4)=8HPOSITION
      I=1
      CALL DRAW(NUMPTS,YONM,XONM,1,0,4H    ,IT,15.,15.,0,3,2,2,6,6,1,
     1LAST)
      CALL DRAW(NUMPTS,YTNMS,XTNMS,2,0,4H    )
      CALL DRAW (2,Y1,X1,2,0,4H    )
      CALL DRAW (2,Y2,X2,3,0,4H    )
      DO 104 I=1,4
  104 IT(I)=8H
      IT(1)=8HGENTZ ND
      IT(2)=8H PLANE A
      IT(3)=8HCTUAL +
      IT(4)=8HNOISE
      I=1
      CALL DRAW(NUMPTS,XONM,ZONM,1,0,4H    ,IT,15.,1.5,0,0,2,2,6,6,1 ,
     1LAST)
      CALL DRAW(NUMPTS,XTNM,ZTNM,2,0,4H    )
      CALL DRAW(NUMPTS,XTNME,ZTNME,3,0,4H    )
      DO 110 I=1,4
  110 IT(I)=8H
      IT(1)=8HGENTZ ND
      IT(2)=8H PLANE S
      IT(3)=8HMOOTHED
      IT(4)=8HPOSITION
      I=1
      CALL DRAW(NUMPTS,XONM,ZONM,1,0,4H    ,IT,15.,1.5,0,0,2,2,6,6,1 ,
     1LAST)
      CALL DRAW(NUMPTS,XTNMS,ZTNMS,2,0,4H    )
      CALL DRAW(2,X1,Z1,2,0,4H    )
      CALL DRAW (2,X2,Z2,3,0,4H    )
  270 CONTINUE
      IF (NGRAF2)281,281,282
  282 CONTINUE
      DO 105 I=1,4
  105 IT(I)=8H
      IT(1)=8HGENTZ RA
      IT(2)=8HNGE SMOO
      IT(3)=8HTHING RE
      IT(4)=8HSULTS
      I=1
      CALL DRAW(NUMPTS,T,RSMO,1,0,4H    ,IT,50.,1.,3,0,2,2,6,6,1,LAST)
      CALL DRAW(NERMAX,TC,RERRP,2,2,4H    )
      CALL DRAW(NERMAX,TC,RERRM,3,2,4H    )
      DO 106 I=1,4
  106 IT(I)=8H
      IT(1)=8HGENTZ NO
      IT(2)=8HRTH SMOO
      IT(3)=8HTHING RE
      IT(4)=8HSULTS
      I=1
      CALL DRAW(NUMPTS,T,ANSMO,1,0,4H    ,IT,50.,.01,3,0,2,2,6,6,1,LAST)
      CALL DRAW(NERMAX,TC,AERRP,2,2,4H    )
      CALL DRAW(NERMAX,TC,AERRM,3,2,4H    )
      DO 116 I=1,4
  116 IT(I)=8H
      IT(1)=8HGENTZ EA
      IT(2)=8HST SMOOT
```

[redacted]

```
      IT(3)=8HHING RES
      IT(4)=8HULTS
      I=1
      CALL DRAW(NUMPTS,T,AESMO,1,0,4H        ,IT,50.,.01,3,0,2,2,6,6,1,LAST)
      CALL DRAW(NERMAX,TC,AERRP,2,2,4H        )
      CALL DRAW(NERMAX,TC,AERRM,3,2,4H        )
      DO 108 I=1,4
  108 IT(I)=8H
      IT(1)=8HGENTZ DO
      IT(2)=8HWN SMOOT
      IT(3)=8HHING RES
      IT(4)=8HULTS
      I=1
      CALL DRAW(NUMPTS,T,ADSMO,1,0,4H        ,IT,50.,.01,3,0,2,2,6,6,1,LAST)
      CALL DRAW(NERMAX,TC,AERRP,2,2,4H        )
      CALL DRAW(NERMAX,TC,AERRM,3,2,4H        )
  281 CONTINUE
      IF (NGRAF3)283,283,284
  284 CONTINUE
      DO 285 I=1,4
  285 IT(I)=8H
      IT(1)=8HGENTZ 3D
      IT(2)=8H RMS SMO
      IT(3)=8HOTHING R
      IT(4)=8HESULTS
      I=1
      CALL DRAW(NUMPTS,T,CIRSMO,1,0,4H        ,IT,50.,.5,0,0,2,2,6,6,1,
     1LAST)
      CALL DRAW(NERMAX,TC,CERRP,3,2,4H        )
  283 CONTINUE
C
C             PRINT STATEMENTS
C
      PRINT 95
   95 FORMAT(1H1,27X17HSMOOTHING RESULTS)
      PRINT 64,(IT(I),I=5,6)
   64 FORMAT(/,32X,2A8)
      PRINT 107
  107 FORMAT(  /,6X66HT=TIME, R NM=ACTUAL RANGE, CIRERR=3DIMENSIONAL RMS
     1 ACTUAL ERROR,      ,/,6X64HCIRSMO=3 DIMENSIONAL RMS SMOOTHED ERROR
     2, ND=1 DETECTION, ND=0 NO,/,6X 68HDETECTION, NQ=QUALITY COUNTER, W
     3HEN NQ=0 TARGET CONSIDERED LOST AND ,/,6X24HALL NINES ARE PRINTED.
     4     )
      PRINT 96
   96 FORMAT(     /,15X1HT,4X4HR NM,7X6HCIRERR,4X6HCIRSMO,2X2HND,
     12X2HNQ)
      PRINT 97,(T(I),RNM(I),CIRERR(I),CIRSMO(I),ND(I),NQ(I),I=1,NUMPTS)
   97 FORMAT ( 7X,1F10.0,3F10.4,2I4)
    2 CONTINUE
  400 STOP
      END
      END
```

[redacted]

Appendix C

Computer Program of Program ALPHA CHECK

Only the smoothing and prediction and output sections are shown since the preceeding portions are the same as in THREE D.

[redacted]

[redacted]

```
 47 IF (RNM(I)-80.)65,66,66
 65 PD=1.55-.016*RNM(I)
    GO TO 52
 66 IF (RNM(I)-110.)62,68,68
 62 PD=.88-.0077*RNM(I)
    GO TO 52
 68 PD=.25+.0019*RNM(I)
 52 CONTINUE
    ADEV=ABSF(DEV)
    ADEV=0.
    IF(PD-ADEV)53,54,54
 53 NQ(I)=0
    GO TO 20
 54 NQ(I)=1
 20 T(I+1)=T(I)+2.
  1 CONTINUE

C                SMOOTHING  COMPUTATIONS

    FPTS=NUMPTS
    NALPH=20

C                RANGE SMOOTHING CONSTANT ANALYSIS

    ALPHAR=.05
    DO 301 J=1,NALPH
    P=1.
    AR(J)=ALPHAR
    ERAR(J)=0.
    DO 305 I=1,NUMPTS
    IF (NQ(I))302,302,303
302 IF(P)304,304,305
304 RNME(I)=RNMP(I)
    RDOTME(I)=RDOTMP(I)
    GO TO 306
303 IF(P)306,306,308
308 P=P-1.
    CTC=T(I)/2.+1.
    RNMP(I)=RNME(I)
    RDOTMP(I)=RDOTME(I)
    RDDOTE(I-1)=0.
306 RDDOTE(I)=RDDOTE(I-1)+1./(2.*Q)*(RDOTME(I)-RDOTMP(I))
    RNMS(I)=RNMP(I)+ALPHAR*(RNME(I)-RNMP(I))
    RNMP(I+1)=RNMS(I)+2.*RDOTME(I)+2.*RDDOTE(I)
    RDOTMP(I+1)=RDOTME(I)+2.*RDDOTE(I)
    RSMO(I)=(RNM(I)-RNMS(I))**2
    ERAR(J)=ERAR(J)+RSMO(I)/(FPTS-CTC)
    IF(NQ(I)) 55,55,56
 55 Q=Q+1.
    GO TO 305
 56 Q=1.
305 CONTINUE
301 ALPHAR=ALPHAR+.05
    I=1
    PRINT 114
114 FORMAT(1H1,17X36HOPTIMUM SMOOTHING CONSTANT ANALYSIS,//,6X62HQUAL
   1TY INDICATOR,THE MINIMUM AVERAGE MEAN SQUARE ERROR             )
    PRINT 604,((IT(I),I=5,6),ANOISE)
604 FORMAT(//,20X,2A8,2X7HANOISE=F4.2)
    PRINT 115
115 FORMAT(//,29X16HRANGE, ALPHAR      )
    PRINT 116,(AR(J),ERAR(J),J=1,NALPH)
```

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```
  116 FORMAT(//,((23X7HALPHAR= F4.2,2X5HERAR=  F6.4)/))

C          NORTH DIRECTION COSINE SMOOTHING CONSTANT ANALYSIS

      ALPHAN=.05
      DO 321 K=1,NALPH
      P=1.
      AN(K)=ALPHAN
      ERAN(K)=0.
      BETAN=ALPHAN**2/(2.-ALPHAN)
      GAMMAN=2.*BETAN/ALPHAN-(ALPHAN+BETAN )
      DO 325 I=1,NUMPTS
      IF(NQ(I))322,322,323
  322 IF(P)324,324,325
  324 DIRNE(I)=DIRNP(I)
      GO TO 326
  323 IF(P)326,326,328
  328 P=P-1.
      DIRNP(I)=DIRNE(I)
      DIRND(I-1)=0.
      DIRNDD(I-1)=0.
  326 DIRND(I)=DIRND(I-1)+2.*DIRNDD(I-1)+BETAN/2.*(DIRNE(I)-DIRNP(I))
      DIRNDD(I)=DIRNDD(I-1)+2.*GAMMAN/4.*(DIRNE(I)-DIRNP(I))
      DIRNS(I)=DIRNP(I)+ALPHAN*(DIRNE(I)-DIRNP(I))
      DIRNP(I+1)=DIRNS(I)+2.*DIRND(I)+2.*DIRNDD(I)
      DNSMO(I)=(DIRN(I)-DIRNS(I))**2
      ERAN(K)=ERAN(K)+DNSMO(I)/(FPTS-CTC)
  325 CONTINUE
  321 ALPHAN=ALPHAN+.05
      I=1
      PRINT 117
  117 FORMAT(//,20X31HNORTH DIRECTION COSINE, ALPHAN   )
      PRINT 118,(AN(K),ERAN(K),K=1,NALPH)
  118 FORMAT(//,((23X7HALPHAN= F4.2,2X5HERAN= F10.8)/))

C               EAST DIRECTION COSINE SMOOTHING CONSTANT ANALYSIS

      ALPHAE=.05
      DO 331 L=1,NALPH
      P=1.
      AE(L)=ALPHAE
      BETAE=ALPHAE**2/(2.-ALPHAE)
      GAMMAE=2.*BETAE/ALPHAE-(ALPHAE+BETAE)
      ERAE(L)=0.
      DO 335 I=1,NUMPTS
      IF (NQ(I))332,332,333
  332 IF(P)334,334,335
  334 DIREP(I)=DIREE(I)
      GO TO 336
  333 IF(P)336,336,338
  338 P=P-1.
      DIREP(I)=DIREE(I)
      DIRED(I-1)=0.
      DIREDD(I-1)=0.
  336 DIRED(I)=DIRED(I-1)+2.*DIREDD(I-1)+BETAE/2.*(DIREE(I)-DIREP(I))
      DIREDD(I)=DIREDD(I-1)+2.*GAMMAE/4 *(DIREE(I)-DIREP(I))
      DIRES(I)=DIREP(I)+ALPHAE*(DIREE(I)-DIREP(I))
      DIREP(I+1)=DIRES(I)+2.*DIRED(I)+2.*DIREDD(I)
      DESMO(I)=(DIRE(I)-DIRES(I))**2
      ERAE(L)==ERAE(L)+DESMO(I)/(FPTS-CTC)
  335 CONTINUE
  331 ALPHAE=ALPHAE+.05
```

[redacted]

```
      I=1
      PRINT 119
  119 FORMAT(1H1,20X31H EAST DIRECTION COSINE, ALPHAE           )
      PRINT 161,(AE(L),ERAE(L),L=1,NALPH)
  161 FORMAT(//,((23X7HALPHAE= F4.2,2X5HERAE= F10.8)/))
C         DOWN DIRECTION COSINE SMOOTHING CONSTANT ANALYSIS
      ALPHAD=.05
      DO 341 M=1,NALPH
      P=1.
      AD(M)=ALPHAD
      BETAD=ALPHAD**2/(2.-ALPHAD)
      GAMMAD=2.*BETAD/ALPHAD-(ALPHAD+BETAD )
      ERAD(M)=0.
      DO 345 I=1,NUMPTS
      IF(NQ(I))342,342,343
  342 IF(P)344,344,345
  344 DIRDE(I)=DIRDP(I)
      GO TO 346
  343 IF(P)346,346,348
  348 P=P-1.
      DIRDP(I)=DIRDE(I)
      DIRDD(I-1)=0.
      DIRDDD(I-1)=0.
  346 DIRDD(I)=DIRDD(I-1)+2.*DIRDDD(I-1)+BETAD/2.*(DIRDE(I)-DIRDP(I))
      DIRDDD(I)=DIRDDD(I-1)+2.*GAMMAD/4.*(DIRDE(I)-DIRDP(I))
      DIRDS(I)=DIRDP(I)+ALPHAD*(DIRDE(I)-DIRDP(I))
      DIRDP(I+1)=DIRDS(I)+2.*DIRDD(I)+2.*DIRDDD(I)
      DDSMO(I)=(DIRD(I)-DIRDS(I))**2
      ERAD(M)=ERAD(M)+DDSMO(I)/(FPTS-CTC)
  345 CONTINUE
  341 ALPHAD=ALPHAD+.05
      I=1
      PRINT 121
  121 FORMAT(//,20X31HDOWN DIRECTION COSINE, ALPHAD  )
      PRINT 123,(AD(M),ERAD(M),M=1,NALPH)
  123 FORMAT(//,((23X7HALPHAD= F4.2,2X5HERAD= F10.8)/))
      IF (NGRAPH)270,270,271
  271 CONTINUE
      DO 110 I=1,4
  110 IT(I)=8H
      IT(1)=8HGENTZ AL
      IT(2)=8HPHAR VS
      IT(3)=8HAVG MEAN
      IT(4)=8HSQ ERROR
      I=1
      CALL DRAW(NALPH,AR,ERAR,0,0,4H    ,IT,.2,0.,0,0,2,2,5,6,1,LAST)
      DO 111 I=1,4
  111 IT(I)=8H
      IT(1)=8HGENTZ AL
      IT(2)=8HPHAN VS
      IT(3)=8HAVG MEAN
      IT(4)=8HSQ ERROR
      I=1
      CALL DRAW(NALPH,AN,ERAN,0,0,4H    ,IT,.2,0.,0,0,2,2,5,6,1,LAST)
      DO 112 I=1,4
  112 IT(I)=8H
      IT(1)=8HGENTZ AL
      IT(2)=8HPHAE VS
      IT(3)=8HAVG MEAN
      IT(4)=8HSQ ERROR
```

APPENDIX C

```
      I=1
      CALL DRAW(NALPH,AE,ERAE,0,0,4H    ,IT,.2,0.,0,0,2,2,5,6,1,LAST)
      DO 113 I=1,4
113   IT(I)=8H
      IT(1)=8HGENTZ AL
      IT(2)=8HPHAD VS
      IT(3)=8HAVG MEAN
      IT(4)=8HSQ ERROR
      I=1
      CALL DRAW(NALPH,AD,ERAD,0,0,4H    ,IT,.2,0.,0,0,2,2,5,6,1,LAST)
270   CONTINUE
      ANOISE=ANOISE+.5
  2   CONTINUE
      END
      END
```

[redacted]

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Appendix C

Results of Runs 2A and 3A

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TABLE VI

SMOOTHING RESULTS

RUN 2A

T=TIME, R NM=ACTUAL RANGE, CIRERR=3DIMENSIONAL RMS ACTUAL ERROR, CIRSMO=3 DIMENSIONAL RMS SMOOTHED ERROR, ND=1 DETECTION, ND=0 NO DETECTION, NQ=QUALITY COUNTER, WHEN NQ=0 TARGET CONSIDERED LOST AND ALL NINES ARE PRINTED.

T	R NM	CIRERR	CIRSMO	ND	NQ
.	14.1508	.2429	.2429	1	2
2.	14.5361	1.8578	.1884	0	1
4.	14.9288	5.1681	2.3338	1	3
6.	15.3280	2.6577	2.4972	1	5
8.	15.7357	.2391	1.3032	1	7
10.	16.1530	3.2430	2.1581	1	9
12.	16.5815	.5384	1.3833	1	10
14.	17.0281	2.8164	.5864	1	10
16.	17.4867	.2840	.4138	1	10
18.	17.9446	3.1760	1.2653	1	10
20.	18.4155	.3837	.6776	1	10
22.	18.8975	1.3631	1.0167	1	10
24.	19.3867	.2607	.4953	1	10
26.	19.8780	.3462	.2626	1	10
28.	20.3618	1.0472	.4439	1	10
30.	20.8512	.4633	.4537	1	10
32.	21.3431	.8665	.6507	1	10
34.	21.8341	3.2078	1.2478	1	10
36.	22.3337	2.3855	.5537	1	10
38.	22.8417	.6766	.2386	1	10
40.	23.3525	2.2829	1.0736	1	10
42.	23.8669	.4162	.7837	1	10
44.	24.3896	.8367	.4905	1	10
46.	24.9098	2.7580	1.1853	1	10
48.	25.4187	1.8427	.4945	1	10
50.	25.9207	1.8184	.8741	1	10
52.	26.4281	2.0666	1.4061	1	10
54.	26.9446	.1707	.7198	1	10
56.	27.4663	.3516	.3665	1	10
58.	27.9841	2.4726	1.2136	1	10
60.	28.4961	2.8985	1.9486	1	10
62.	29.0163	.9102	.8421	1	10
64.	29.5405	2.4250	1.5345	1	10
66.	30.0547	.2888	.7757	1	10
68.	30.5636	2.8572	1.0178	1	10
70.	31.0732	1.1682	.7910	1	10
72.	31.5752	2.5874	.9229	1	10
74.	32.0719	4.1386	.9257	0	9
76.	32.5737	4.3305	.9190	0	8
78.	33.0744	.7393	.2930	1	10
80.	33.5744	.4837	.2606	1	10
82.	34.0735	3.1434	1.3395	1	10
84.	34.5622	6.2619	2.0776	1	10
86.	35.0347	1.3708	1.6499	1	10
88.	35.4993	1.3935	.3853	1	10
90.	35.9716	2.2291	1.1751	1	10
92.	36.4471	.8413	.9765	1	10
94.	36.9205	4.1630	1.0170	0	9
96.	37.4029	.7908	1.0545	0	8
98.	37.8898	2.9077	1.8114	1	10
100.	38.3598	2.2822	1.9747	1	10

[redacted]

102.	38.8208	1.2352	1.6414	1	10
104.	39.2771	1.0081	1.6821	0	9
106.	39.7219	1.3226	1.7492	0	8
108.	40.1699	2.5017	.6377	1	10
110.	40.6274	1.5599	.7224	0	9
112.	41.0975	1.1474	.3996	1	10
114.	41.5831	2.4063	.9575	1	10
116.	42.0766	2.8075	1.7263	1	10
118.	42.5788	2.0830	1.8448	1	10
120.	43.0949	1.6373	1.0452	1	10
122.	43.6149	3.9712	1.5931	1	10
124.	44.1265	3.5972	.9488	1	10
126.	44.6289	1.1772	.9773	1	10
128.	45.1289	2.5394	1.0695	0	9
130.	45.6308	4.0954	1.6265	1	10
132.	46.1254	3.1991	1.6298	0	9
134.	46.6149	3.7560	1.6372	0	8
136.	47.1069	1.7349	.4193	1	10
138.	47.6015	4.5316	.5815	0	9
140.	48.1068	1.5873	.7846	1	10
142.	48.6124	3.4682	.9627	0	9
144.	49.1099	4.5222	1.9443	1	10
146.	49.6123	2.4393	1.9411	1	10
148.	50.1305	1.1182	1.4023	1	10
150.	50.6560	2.0418	1.1725	1	10
152.	51.1413	1.4302	.9893	1	10
154.	51.5500	3.1677	.9586	0	9
156.	51.8594	5.5666	2.8916	1	10
158.	52.0482	4.1646	.2635	1	10
160.	52.1140	1.8953	.8238	1	10
162.	52.0591	3.4264	2.0061	1	10
164.	51.9006	5.1728	1.1369	1	10
166.	51.6697	1.1559	1.0252	1	10
168.	51.3834	5.7135	1.0221	0	9
170.	51.0395	.6025	.6973	1	10
172.	50.6556	1.1781	.9878	1	10
174.	50.2446	2.0658	1.2707	0	9
176.	49.8208	4.6100	1.2732	1	10
178.	49.3989	3.2128	2.0423	1	10
180.	48.9821	4.2528	1.9403	0	9
182.	48.5692	1.0591	1.3613	1	10
184.	48.1119	2.1753	1.4066	0	9
186.	47.5735	2.5240	1.5005	0	8
188.	46.9689	2.4412	1.3493	1	10
190.	46.3166	.7867	1.3113	0	9
192.	45.6382	1.7295	1.2334	1	10
194.	44.9558	.9434	.6980	1	10
196.	44.2740	.4483	.5947	1	10
198.	43.5920	2.8470	.7076	0	9
200.	42.9103	1.1029	.9519	1	10
202.	42.2292	2.2757	1.1051	0	9
204.	41.5480	1.7588	.9635	1	10
206.	40.8671	2.3066	.9918	0	9
208.	40.1867	3.8105	2.1570	1	10
210.	39.5063	3.1534	2.1457	0	9
212.	38.8259	1.0573	.7847	1	10
214.	38.1459	1.5897	1.0460	1	10
216.	37.4664	1.3193	1.0607	0	9
218.	36.7869	.5547	1.0738	0	8
220.	36.1085	1.0087	.2027	1	10
222.	35.4303	2.1346	.8276	1	10
224.	34.7529	1.3110	1.0649	1	10

[redacted]

[redacted]

TABLE VI

226.	34.0749	2.1787	.6855	1	10
228.	33.3975	.4082	.5342	1	10
230.	32.7206	1.3724	.8840	1	10
232.	32.0440	2.1839	.6753	1	10
234.	31.3678	2.7252	.9610	1	10
236.	30.6924	3.6988	1.1270	1	10
238.	30.0179	.7710	.5272	1	10
240.	29.3435	.7381	.4593	1	10
242.	28.6691	2.6855	1.1992	1	10
244.	27.9965	6.0145	3.3541	1	10
246.	27.3240	.7808	1.7433	1	10
248.	26.6523	3.5173	1.7405	0	9
250.	25.9817	.7993	1.2639	1	10
252.	25.3124	2.2336	.3740	1	10
254.	24.6440	.9793	.3205	1	10
256.	23.9762	3.1969	1.3033	1	10
258.	23.3099	4.0120	1.1218	1	10
260.	22.6455	4.3144	2.5606	1	10
262.	21.9819	2.9578	2.7006	1	10
264.	21.3204	2.5896	2.6388	1	10
266.	20.6607	2.9779	.1962	1	10
268.	20.0023	5.9153	2.7239	1	10
270.	19.3461	1.0316	1.9358	1	10
272.	18.6925	3.2929	.4368	1	10
274.	18.0411	3.2258	1.2219	1	10
276.	17.3924	.1839	.7240	1	10
278.	16.7475	1.0062	.0602	1	10
280.	16.1055	3.8057	1.7427	1	10
282.	15.4672	4.8647	1.2413	1	10
284.	14.8336	.6335	.4280	1	10
286.	14.2050	.9860	.6522	1	10
288.	13.5825	1.6242	.3983	1	10
290.	12.9671	4.7467	2.3462	1	10
292.	12.3584	.9923	1.7011	1	10
294.	11.7589	2.1678	.1597	1	10
296.	11.1693	.8452	.4479	1	10
298.	10.5914	2.4414	.8965	1	10
300.	10.0282	.9809	.9373	0	9

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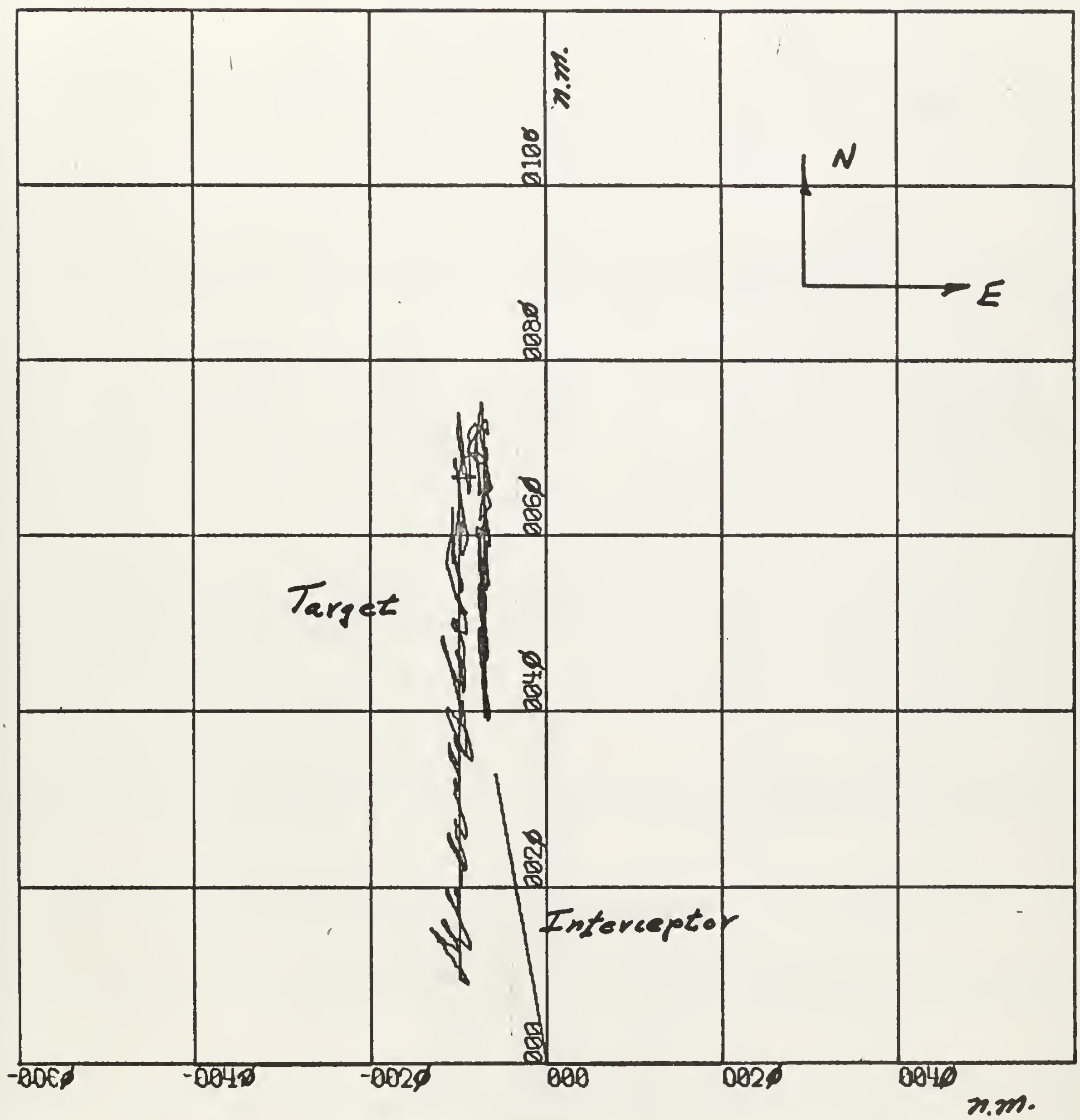
FIGURE 16



X-SCALE = 2.00E+01 UNITS/INCH.
Y-SCALE = 2.00E+01 UNITS/INCH.

GENTZ NE: PLANE ACTUAL + NOISE RUN 2A

[redacted]

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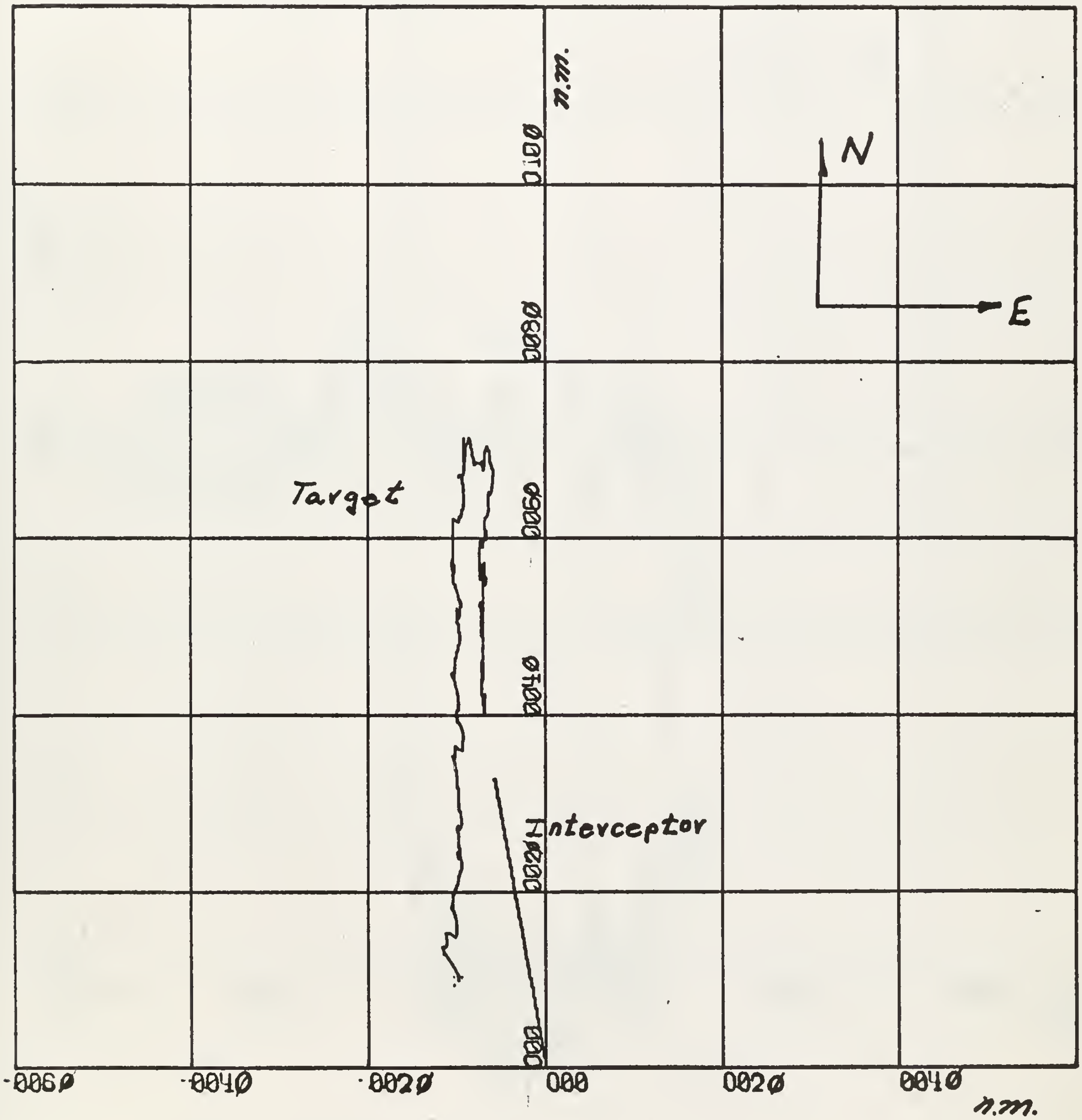
FIGURE 17



X-SCALE = 2.00E+01 UNITS/INCH.
Y-SCALE = 2.00E+01 UNITS/INCH.

GENTZ NE PLANE SMOOTHED POSITION RUN 2A

[redacted]

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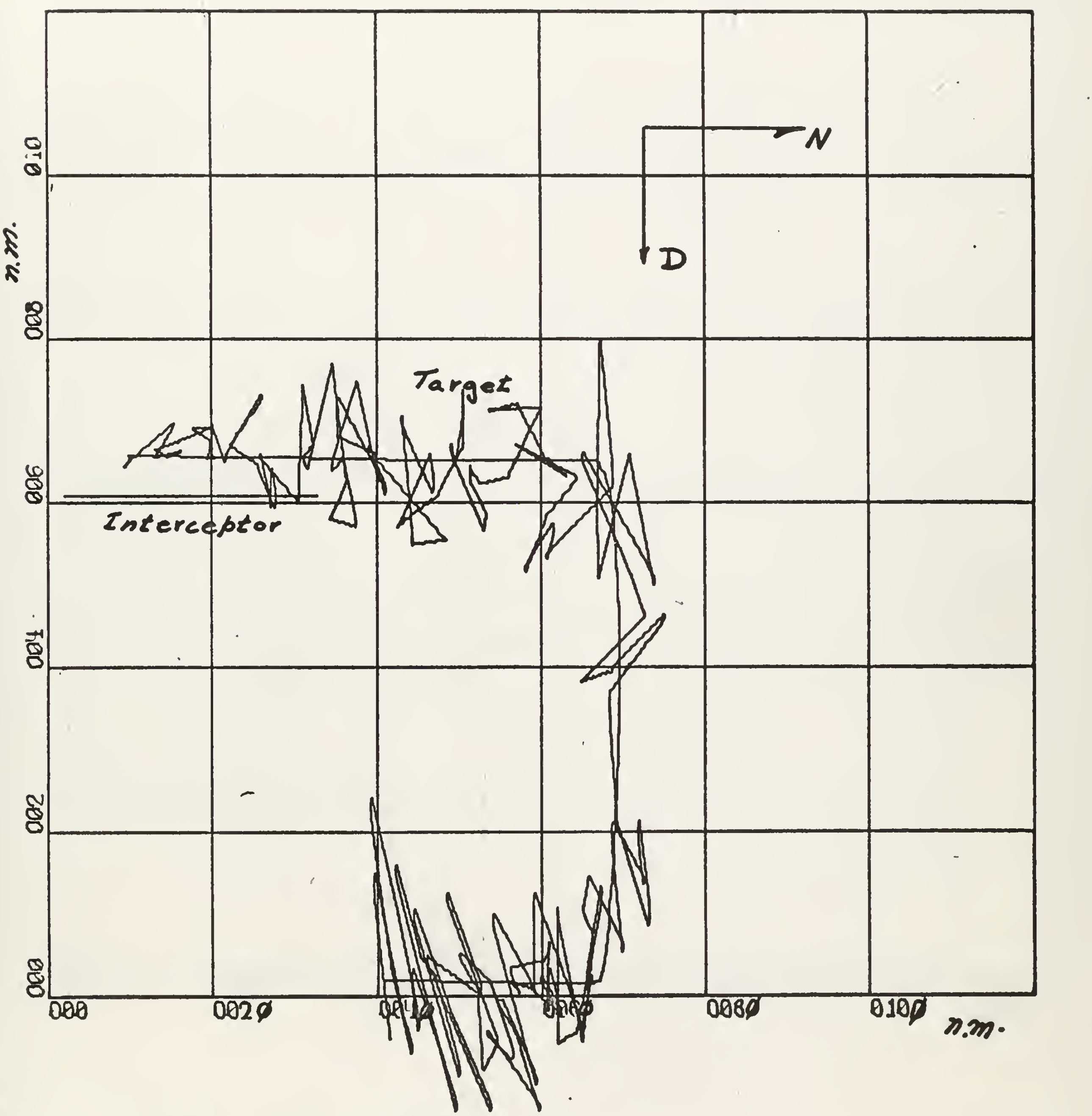
FIGURE 18



X-SCALE = 2.00E+01 UNITS/INCH
Y-SCALE = 2.00E+00 UNITS/INCH

GENTZ ND PLANE ACTUAL + NOISE RUN 2A

[redacted]

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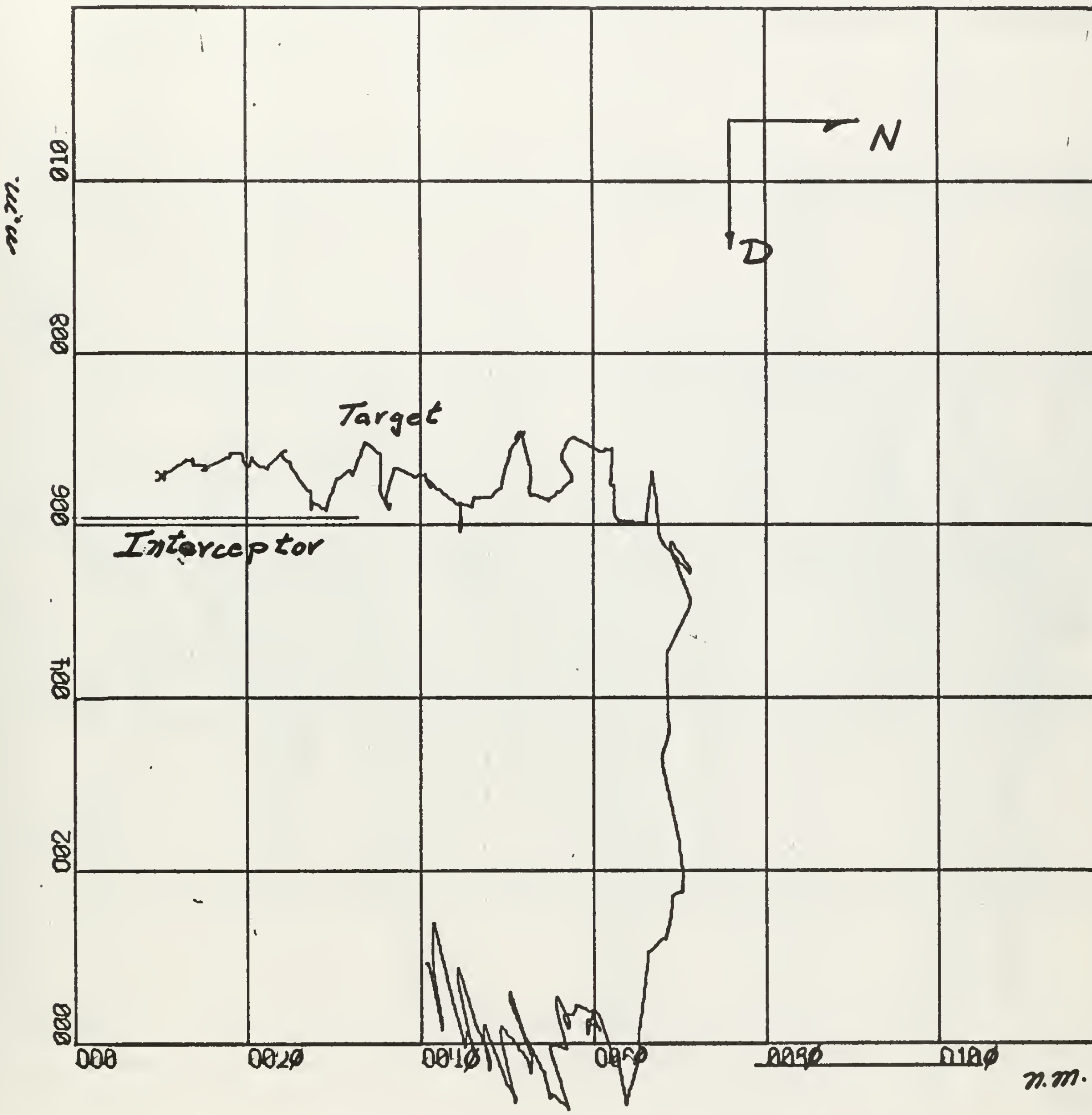
FIGURE 19



X-SCALE = 2.00E+01 UNITS/INCH.
Y-SCALE = 2.00E+00 UNITS/INCH.

GENTZ ND-PLANE SMOOTHED POSITION RUN 2A

[redacted]

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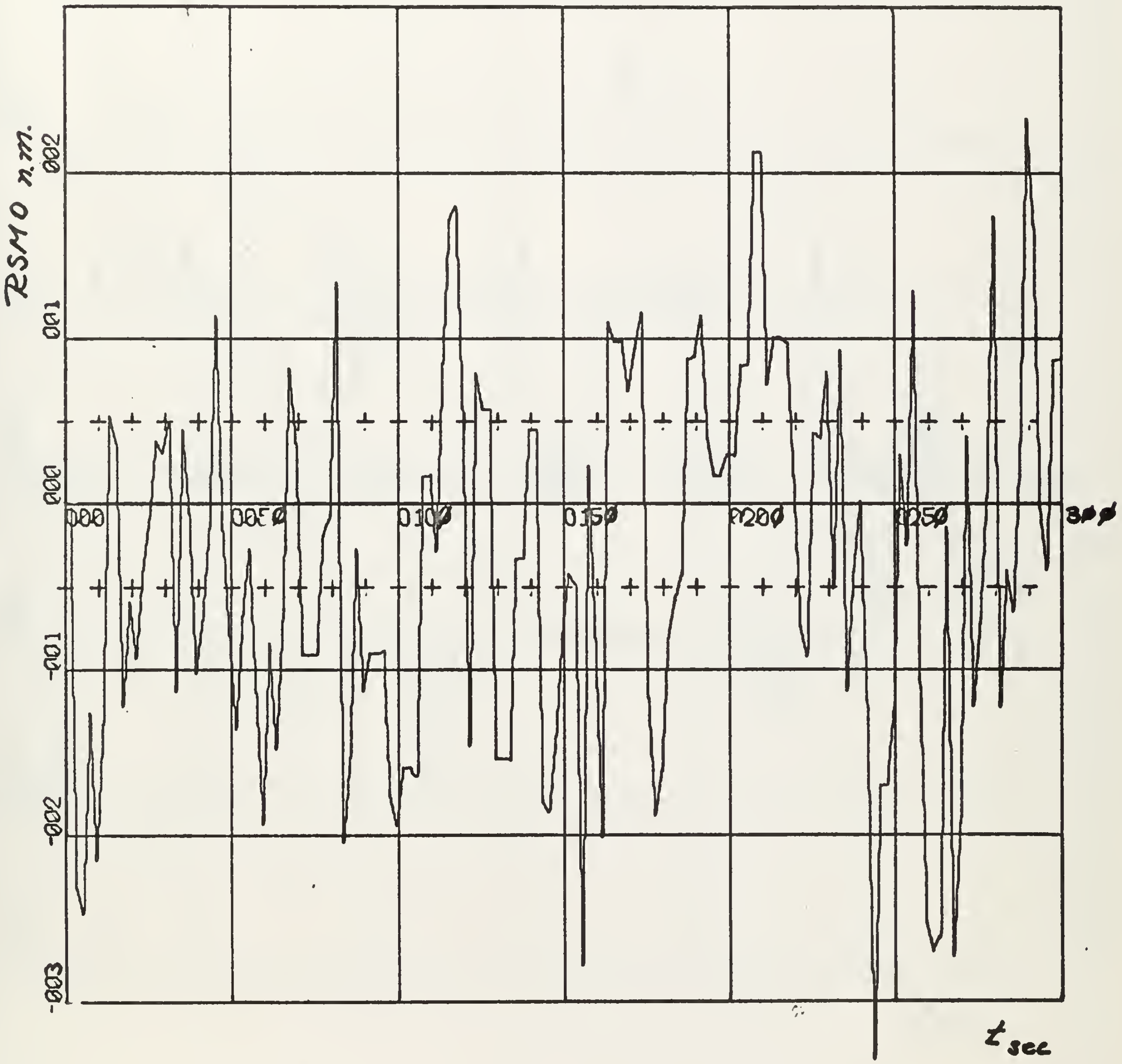
[redacted]

FIGURE 20



X-SCALE = 5.00E+01 UNITS/INCH
Y-SCALE = 1.00E+00 UNITS/INCH
GENTZ RANGE SMOOTHING RESULTS RUN 2A

[redacted]

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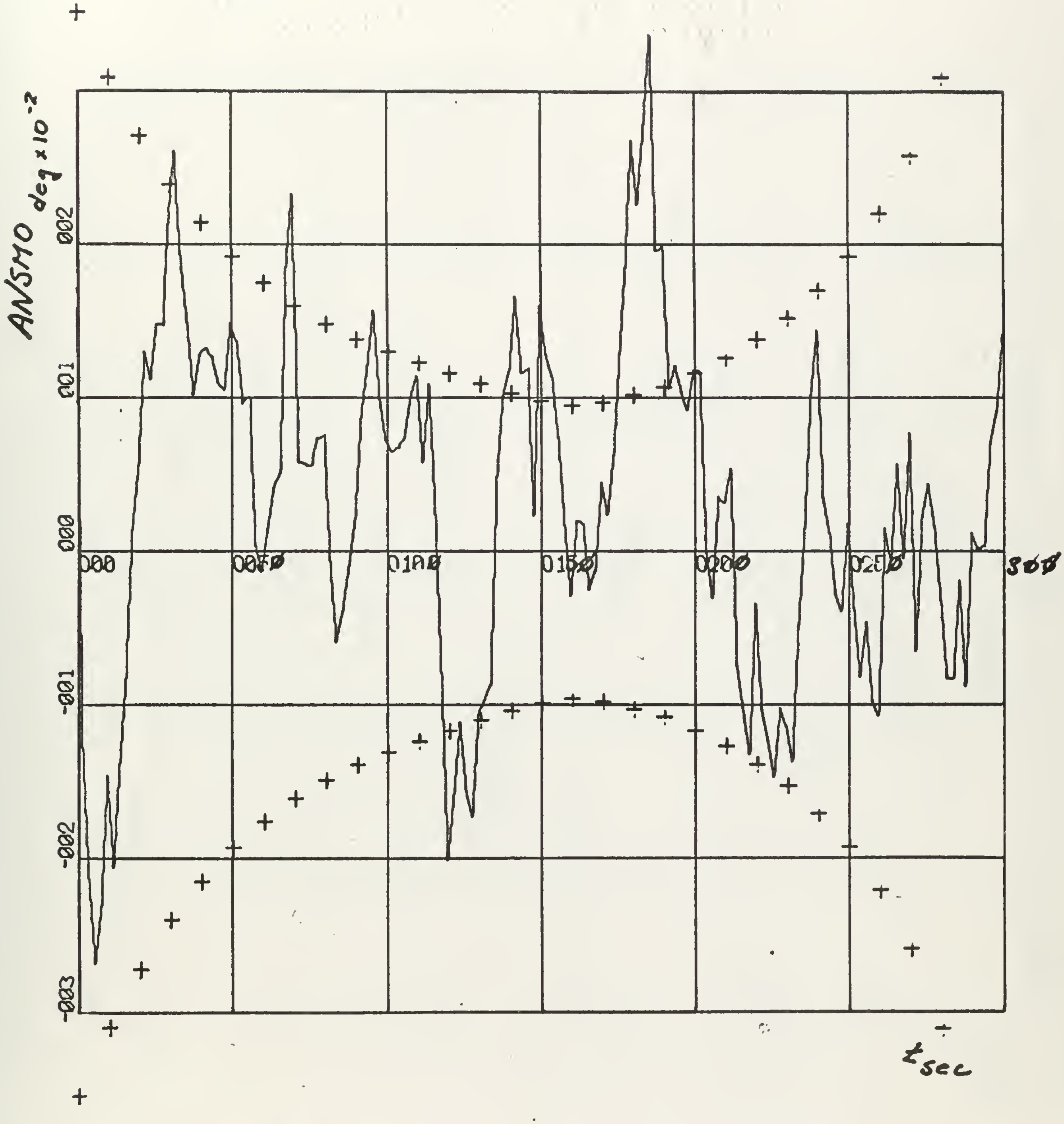
FIGURE 21



X-SCALE = 5.00E+01 UNITS/INCH.
Y-SCALE = 1.00E-02 UNITS/INCH.

GENTZ-NORTH SMOOTHING RESULTS   RUN 2A

[redacted]

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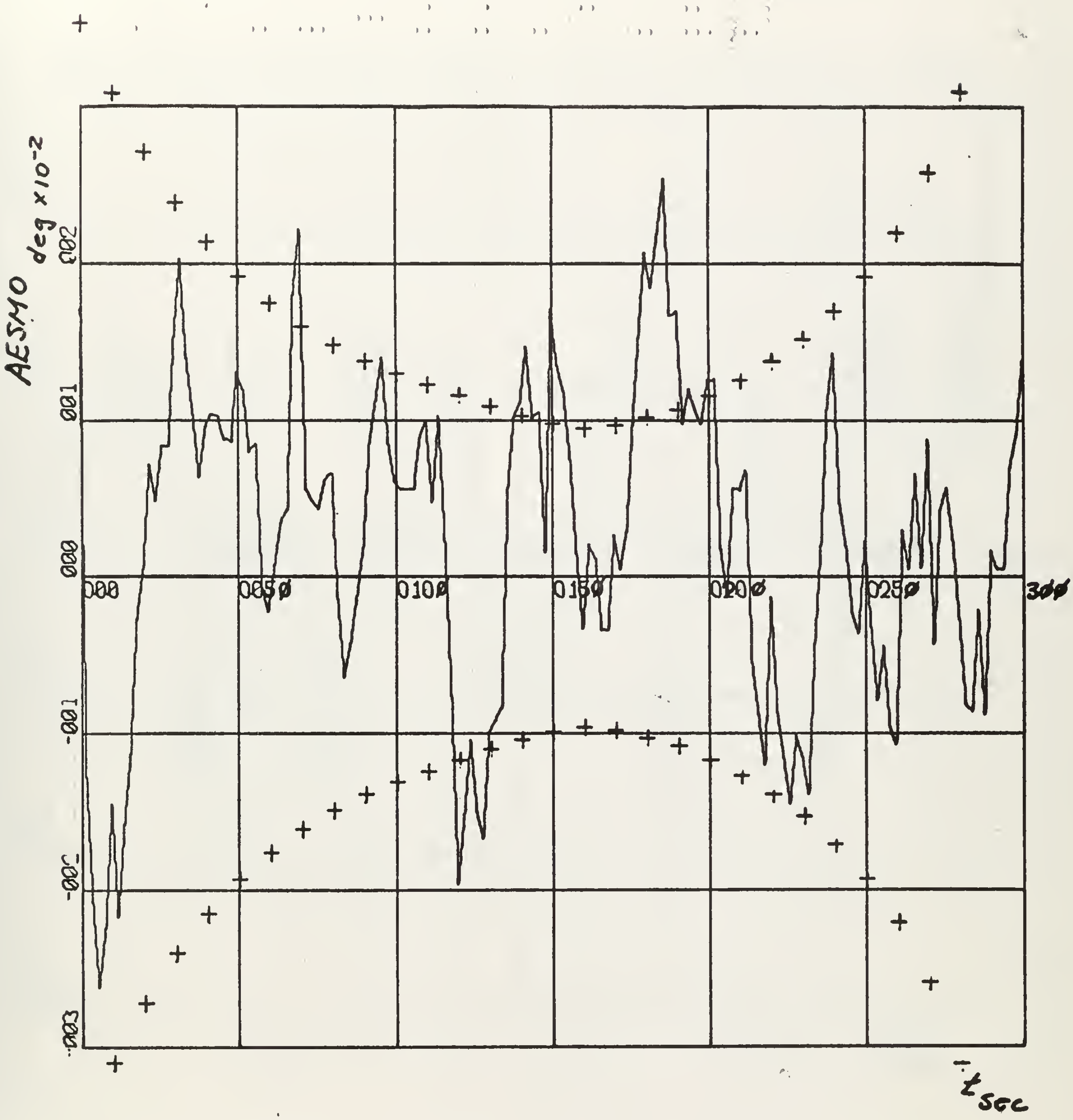
FIGURE 22



X-SCALE = 5.00E+01 UNITS/INCH.
Y-SCALE = 1.00E-02 UNITS/INCH.

GENTZ EAST SMOOTHING RESULTS RUN 2A

[redacted]

[redacted]

FIGURE 23

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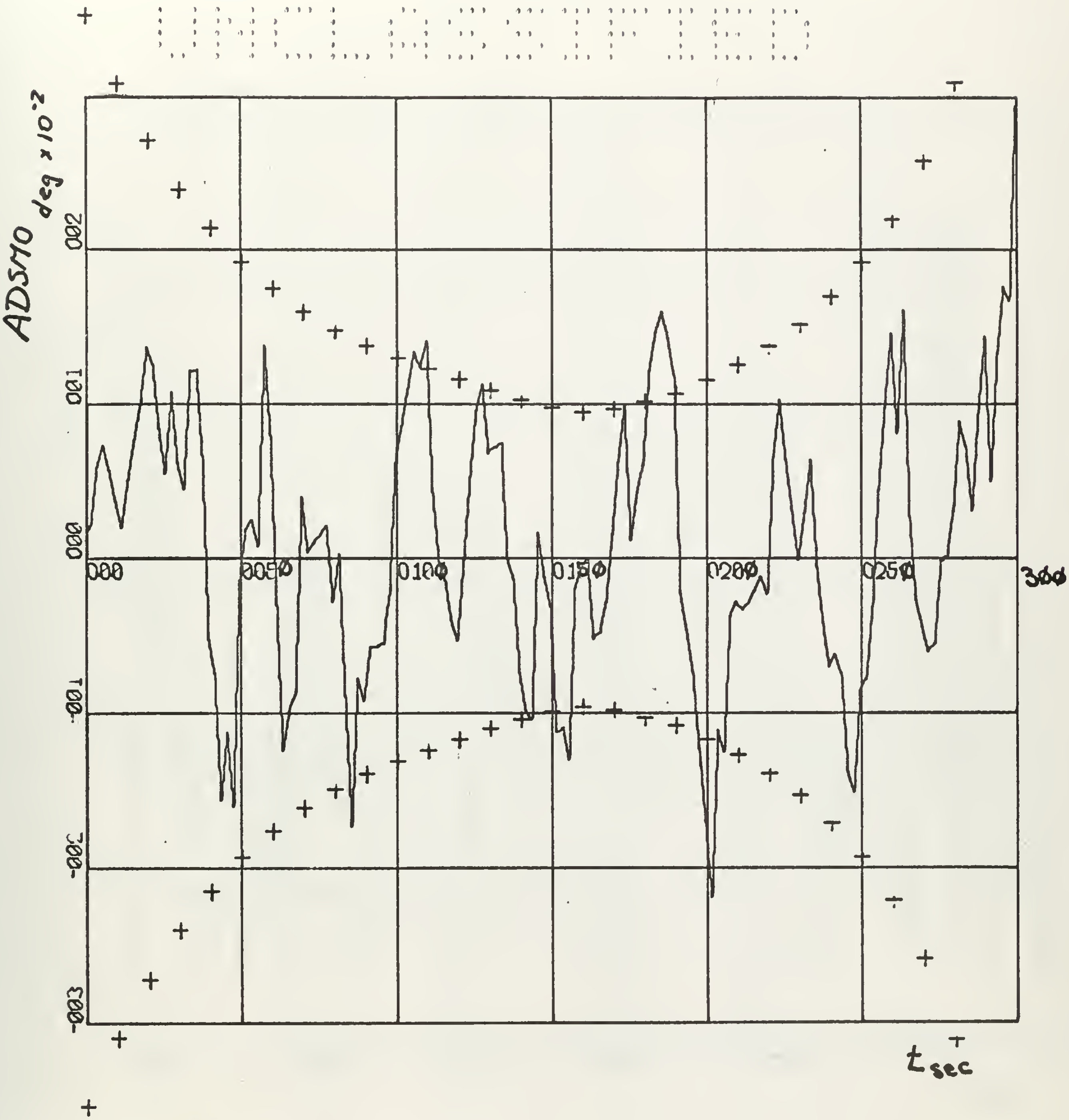

X-SCALE = 5.00E+01 UNITS/INCH.
Y-SCALE = 1.00E-02 UNITS/INCH.

GENTZ DOWN SMOOTHING RESULTS RUN 2A

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FIGURE 24

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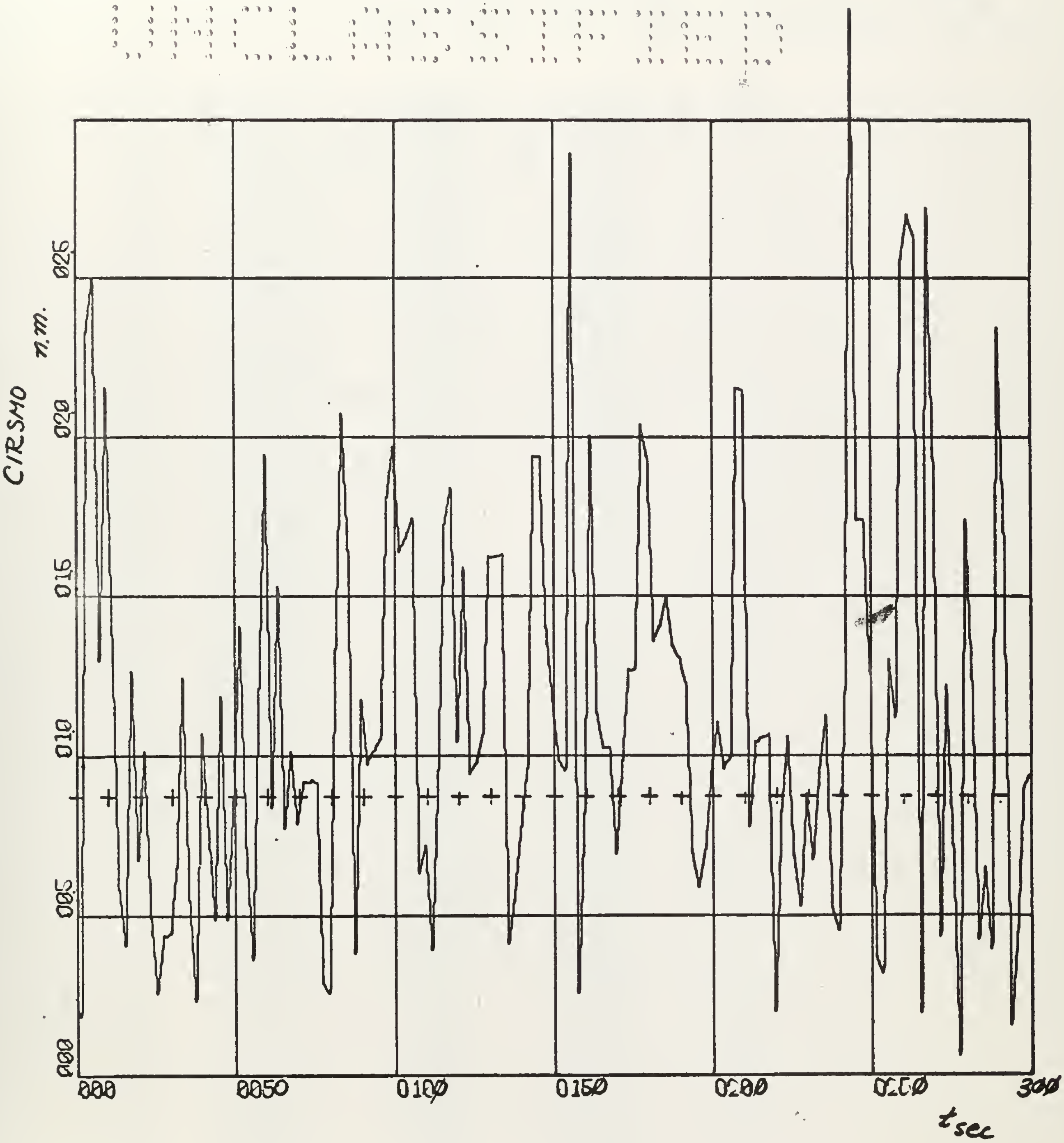

X-SCALE = 5.00E+01 UNITS/INCH.
Y-SCALE = 5.00E-01 UNITS/INCH.

GENTZ 3D RMS SMOOTHING RESULTS RUN 2A

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[redacted]

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TABLE VII

SMOOTHING RESULTS

[redacted]

RUN 3A

T=TIME, R NM=ACTUAL RANGE, CIRERR=3DIMENSIONAL RMS ACTUAL ERROR, CIRSMO=3 DIMENSIONAL RMS SMOOTHED ERROR, ND=1 DETECTION, ND=0 NO DETECTION, NQ=QUALITY COUNTER, WHEN NQ=0 TARGET CONSIDERED LOST AND ALL NINES ARE PRINTED.

T	R NM	CIRERR	CIRSMO	ND	NQ
.	64.0331	999.9999	999.9999	99	0
2.	63.3432	999.9999	999.9999	99	0
4.	62.6615	5.2284	5.2284	1	2
6.	61.9874	2.7182	4.6090	1	4
8.	61.3185	.2872	5.5982	0	3
10.	60.6536	3.2794	6.6195	0	2
12.	59.9917	1.6075	7.6619	0	1
14.	59.3272	2.8920	3.6603	1	3
16.	58.6651	.7415	4.6221	0	2
18.	58.0138	3.2788	5.5782	0	1
20.	57.3638	999.9999	999.9999	99	0
22.	56.7166	1.5299	1.5299	1	2
24.	56.0745	.3846	2.2500	0	1
26.	55.4404	.5298	1.5796	1	3
28.	54.8201	1.5294	1.0911	1	5
30.	54.2051	1.0748	.8828	1	7
32.	53.5976	1.3123	1.6640	0	6
34.	52.9995	3.4929	2.8562	1	8
36.	52.4058	2.4402	1.1354	1	10
38.	51.8165	.7161	1.2831	1	10
40.	51.2350	2.6550	2.0668	1	10
42.	50.6614	.6466	1.7287	1	10
44.	50.0936	1.4282	2.4901	0	9
46.	49.5372	2.7713	.6522	1	10
48.	48.9957	2.0566	1.2807	0	9
50.	48.4667	2.3367	1.9261	0	8
52.	47.9451	2.1026	2.3270	1	10
54.	47.4298	.1763	1.5481	1	10
56.	46.9230	.5103	1.1057	1	10
58.	46.4283	2.8799	1.9722	1	10
60.	45.9465	2.9172	2.5485	0	9
62.	45.4729	1.2985	3.1176	0	8
64.	45.0096	2.6134	2.9528	1	10
66.	44.5609	.3172	1.7675	1	10
68.	44.1256	3.0541	.5865	1	10
70.	43.7018	1.6328	.9893	1	10
72.	43.2920	2.6931	1.5273	1	10
74.	42.8956	4.2163	1.9088	0	9
76.	42.5102	4.3487	2.2854	0	8
78.	42.1371	.7797	1.1668	1	10
80.	41.7768	.6017	.8212	1	10
82.	41.4294	3.1609	.8167	1	10
84.	41.0970	6.2959	2.5325	1	10
86.	40.7797	1.5041	2.0367	1	10
88.	40.4761	1.4301	.6766	1	10
90.	40.1844	2.2406	1.4451	1	10
92.	39.9054	.8812	1.1853	1	10
94.	39.6402	4.1764	1.3252	0	9
96.	39.3887	.8162	1.4454	0	8
98.	39.1518	2.9079	2.1325	1	10
100.	38.9300	2.2865	2.1741	1	10
102.	38.7226	1.2349	1.7783	1	10

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104.	38.5297	.9965	1.8432	0	9
106.	38.3503	1.3215	1.9278	0	8
108.	38.1848	2.4956	.5250	1	10
110.	38.0346	1.5309	.5820	0	9
112.	37.9008	1.1135	.4883	1	10
114.	37.7849	2.3822	.7989	1	10
116.	37.6863	2.8018	1.6387	1	10
118.	37.6061	2.0159	1.7803	1	10
120.	37.5459	1.4986	.9739	1	10
122.	37.5045	3.9605	1.6202	1	10
124.	37.4788	3.5794	.9011	1	10
126.	37.4685	1.0004	.8735	1	10
128.	37.4751	2.5266	.9217	0	9
130.	37.4993	4.0935	1.6939	1	10
132.	37.5383	3.1103	1.7536	0	9
134.	37.5921	3.7243	1.8317	0	8
136.	37.6634	1.5543	.5339	1	10
138.	37.7527	4.4405	.6837	0	9
140.	37.8630	1.5008	.5356	1	10
142.	37.9903	3.3820	1.6679	1	10
144.	38.1305	4.5163	1.3734	1	10
146.	38.2891	2.2521	1.6145	1	10
148.	38.4717	1.0184	1.2851	1	10
150.	38.6742	1.5588	.9766	1	10
152.	38.8196	1.0862	.8368	1	10
154.	38.8491	3.1644	.8925	0	9
156.	38.7656	5.5166	2.8681	1	10
158.	38.5776	4.1332	.4266	1	10
160.	38.3053	1.8729	.7371	1	10
162.	37.9787	3.3661	1.9108	1	10
164.	37.6361	5.1068	1.3710	1	10
166.	37.3107	1.0431	1.2419	1	10
168.	36.9799	5.6588	1.4940	0	9
170.	36.6259	.4481	1.1520	1	10
172.	36.2803	1.1135	1.2744	1	10
174.	35.9586	1.5451	1.6284	0	9
176.	35.6751	4.5126	1.2923	1	10
178.	35.4273	3.1534	2.0551	1	10
180.	35.1865	4.2473	1.9926	0	9
182.	34.9512	.7718	1.3195	1	10
184.	34.6887	2.1744	1.3184	0	9
186.	34.3714	2.3991	1.2573	1	10
188.	34.0072	2.4130	1.6659	1	10
190.	33.6073	.6771	1.6882	0	9
192.	33.1834	1.6046	1.5719	1	10
194.	32.7565	.7703	.8252	1	10
196.	32.3302	.3318	.6356	1	10
198.	31.9053	2.6663	.7830	0	9
200.	31.4831	.8586	.9181	1	10
202.	31.0616	2.0547	1.2914	1	10
204.	30.6429	1.6486	1.3221	1	10
206.	30.2249	2.2947	1.3599	0	9
208.	29.8092	3.7582	2.3422	1	10
210.	29.3963	3.1228	2.6788	1	10
212.	28.9854	1.0196	1.0493	1	10
214.	28.5769	1.4864	1.2071	1	10
216.	28.1695	1.2797	.1447	1	10
218.	27.7643	.5272	.1242	0	9
220.	27.3634	.9118	.4105	1	10
222.	26.9647	2.0230	1.0156	1	10
224.	26.5680	1.2445	1.1168	1	10

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TABLE VII

226.	26.1748	2.1479	.4756	1	10
228.	25.7845	.3876	.4112	1	10
230.	25.3963	1.3388	.8052	1	10
232.	25.0123	2.1512	.6203	1	10
234.	24.3301	2.7101	.9254	1	10
236.	24.2535	3.6820	1.1451	1	10
238.	23.8804	.6717	.5093	1	10
240.	23.5097	.6755	.3905	1	10
242.	23.1429	2.6744	1.2051	1	10
244.	22.7823	6.0123	3.3630	1	10
246.	22.4258	.6651	1.7443	1	10
248.	22.0740	3.5154	1.7565	0	9
250.	21.7261	.7764	1.2941	1	10
252.	21.3833	2.2259	.3464	1	10
254.	21.0473	.9641	.3039	1	10
256.	20.7154	3.1924	1.2741	1	10
258.	20.3910	4.0046	1.1196	1	10
260.	20.0734	4.3098	2.5728	1	10
262.	19.7619	2.9459	2.7294	1	10
264.	19.4577	2.5792	2.6587	1	10
266.	19.1605	2.9675	.2325	1	10
268.	18.8707	5.9137	2.7529	1	10
270.	18.5874	1.0253	1.9724	1	10
272.	18.3143	3.2915	.4318	1	10
274.	18.0479	3.2258	1.2655	1	10
276.	17.7910	.1867	.7666	1	10
278.	17.5437	1.0069	.1274	1	10
280.	17.3071	3.8062	1.7151	1	10
282.	17.0794	4.8666	1.2698	1	10
284.	16.8624	.6385	.4451	1	10
286.	16.6565	.9990	.7002	1	10
288.	16.4640	1.6364	.3428	1	10
290.	16.2820	4.7497	2.3317	1	10
292.	16.1119	1.0382	1.7219	1	10
294.	15.9560	2.1743	.0442	1	10
296.	15.8117	.8606	.3557	1	10
298.	15.6809	2.4438	.9915	1	10
300.	15.5659	1.0195	1.1565	0	9

[redacted]

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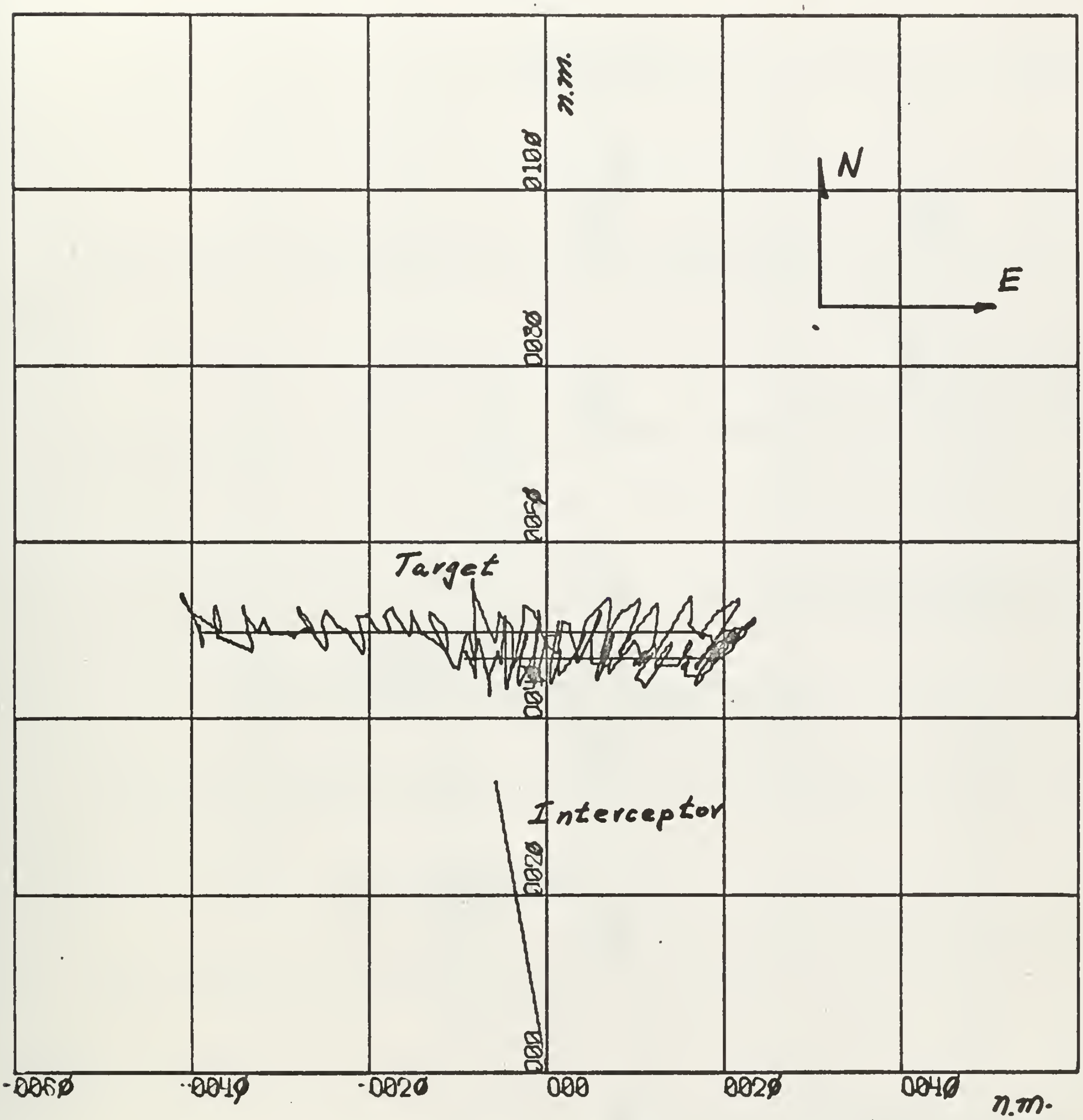
FIGURE 25



X-SCALE = 2.00E+01 UNITS/INCH.
Y-SCALE = 2.00E+01 UNITS/INCH.

GENTZ NE PLANE ACTUAL + NOISE RUN 3A

[redacted]

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[redacted]

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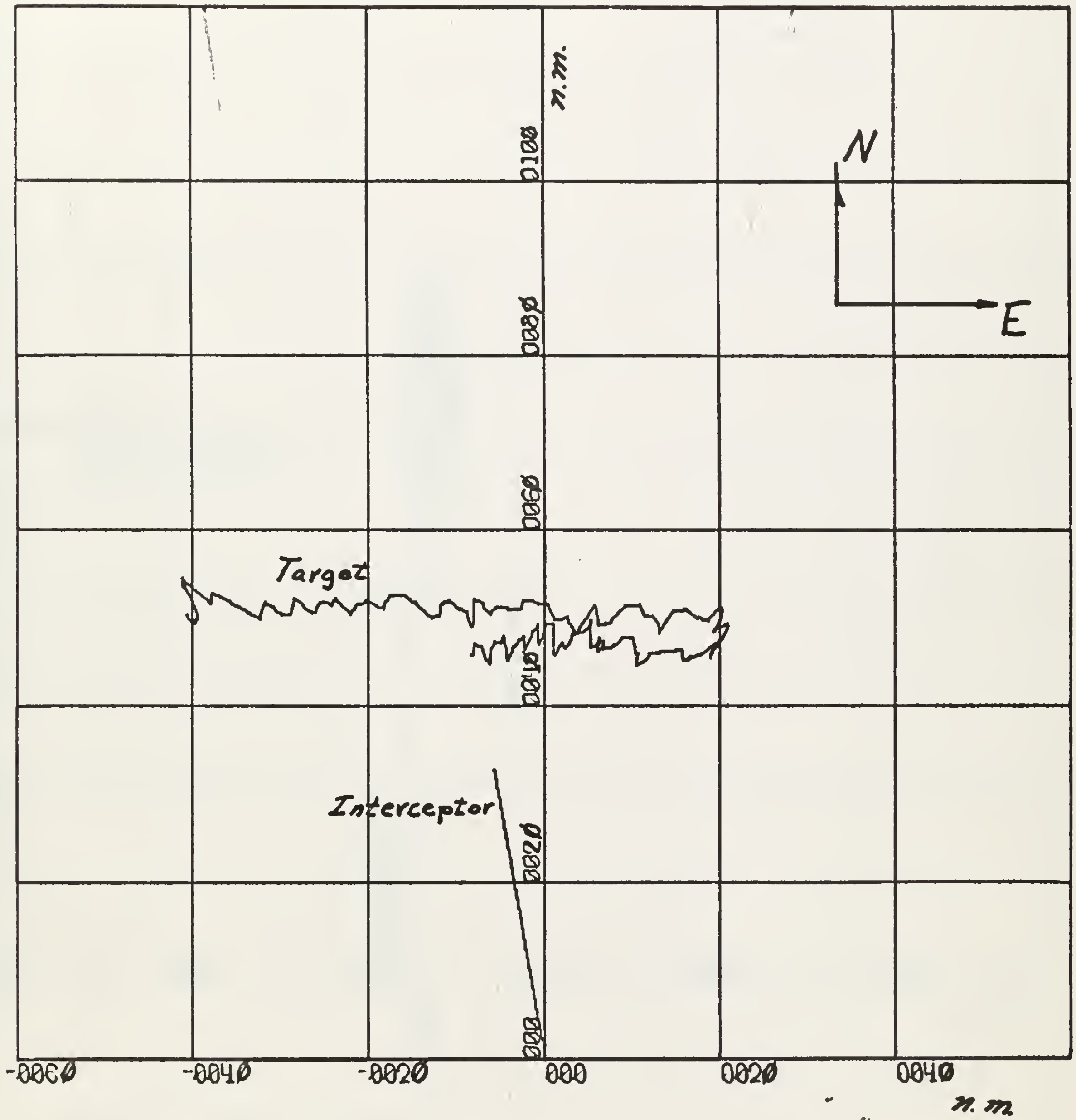
FIGURE 26



X-SCALE = 2.00E+01 UNITS/INCH.
Y-SCALE = 2.00E+01 UNITS/INCH.
GENTZ NE PLANE SMOOTHED POSITION RUN 3A

[redacted]

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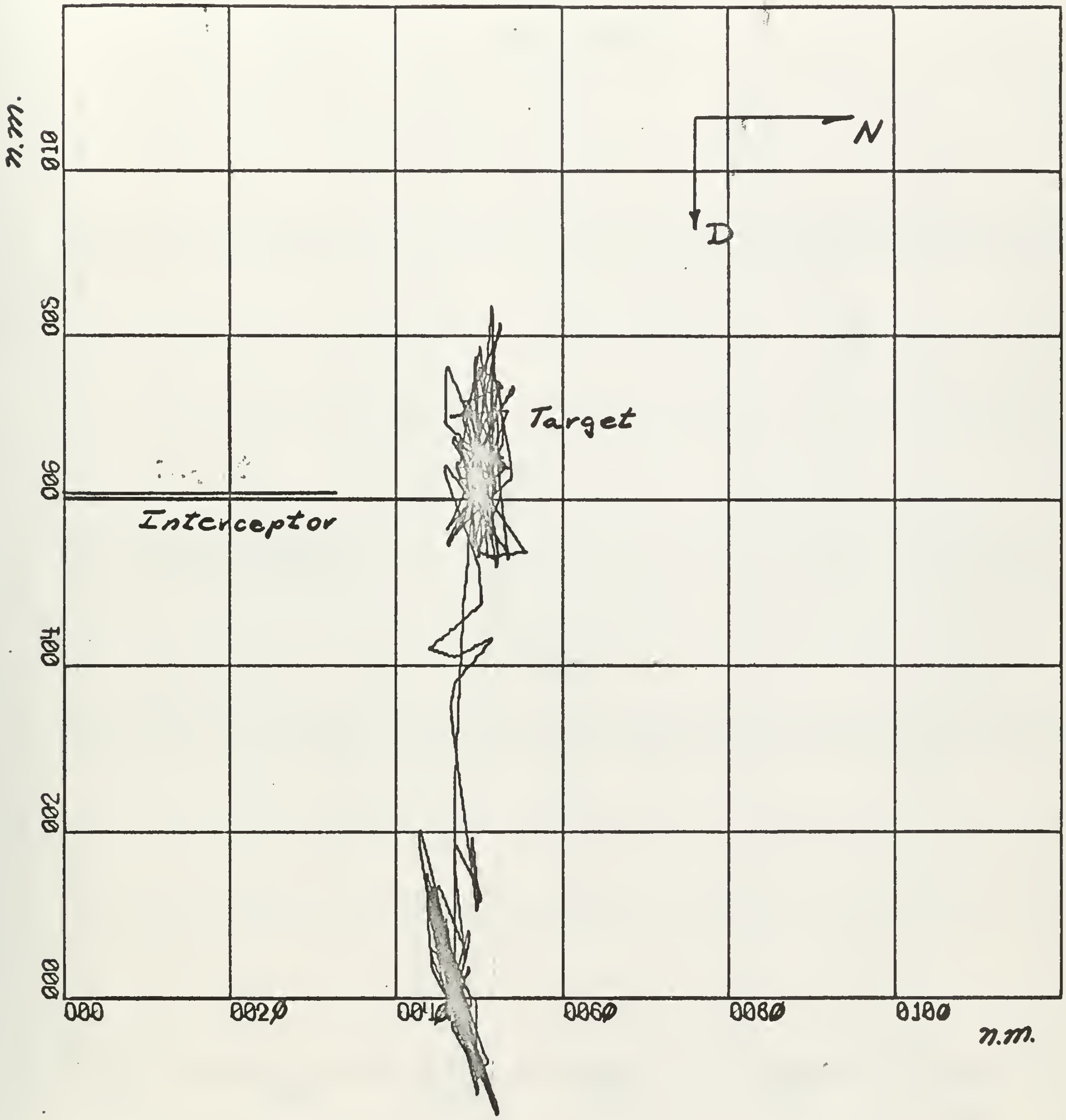
FIGURE 27



X-SCALE = 2.00E+01 UNITS/INCH.
Y-SCALE = 2.00E+00 UNITS/INCH.

GENTZ ND PLANE ACTUAL + NOISE RUN 3A

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[redacted]

[redacted]

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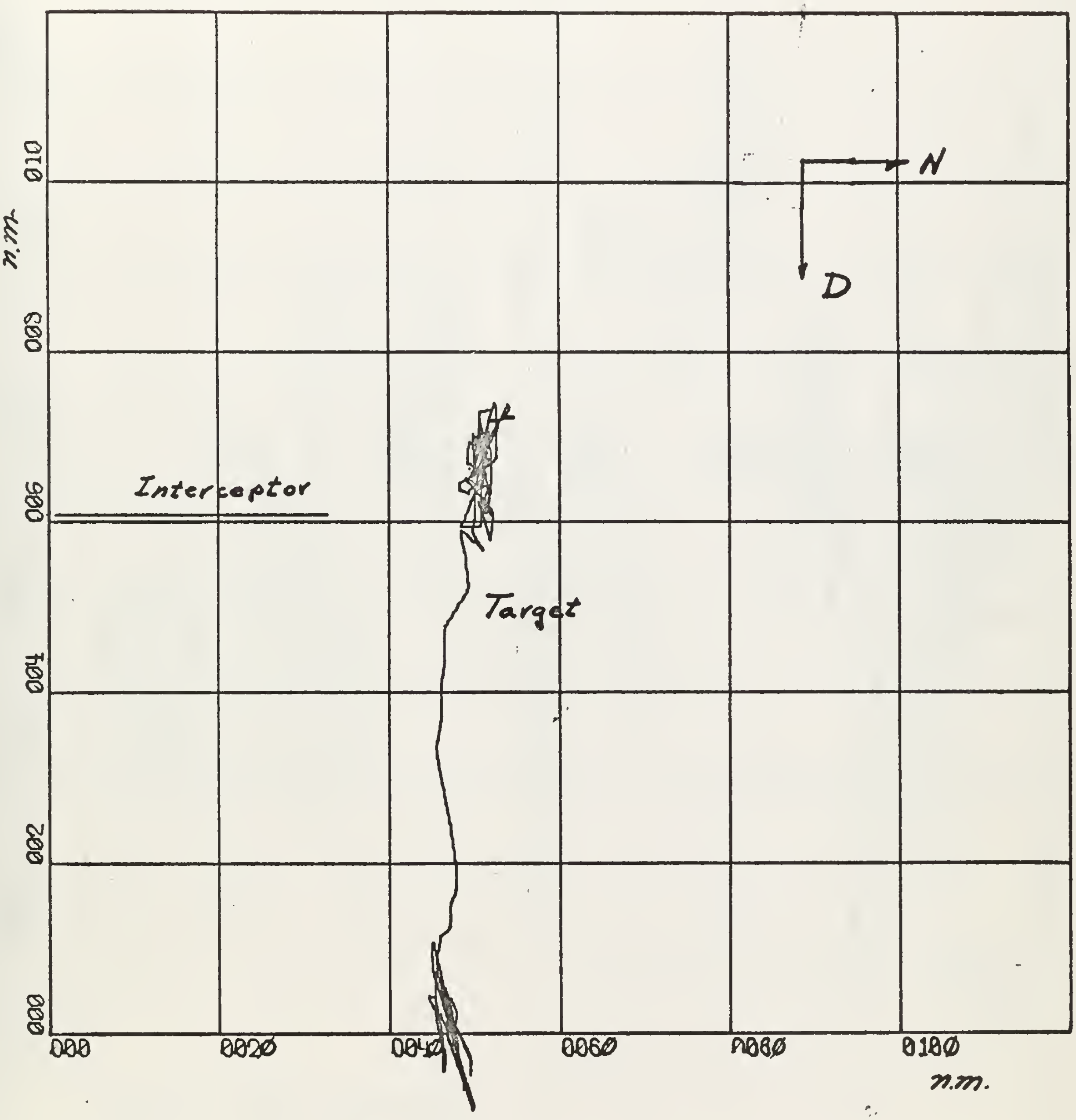
FIGURE 28

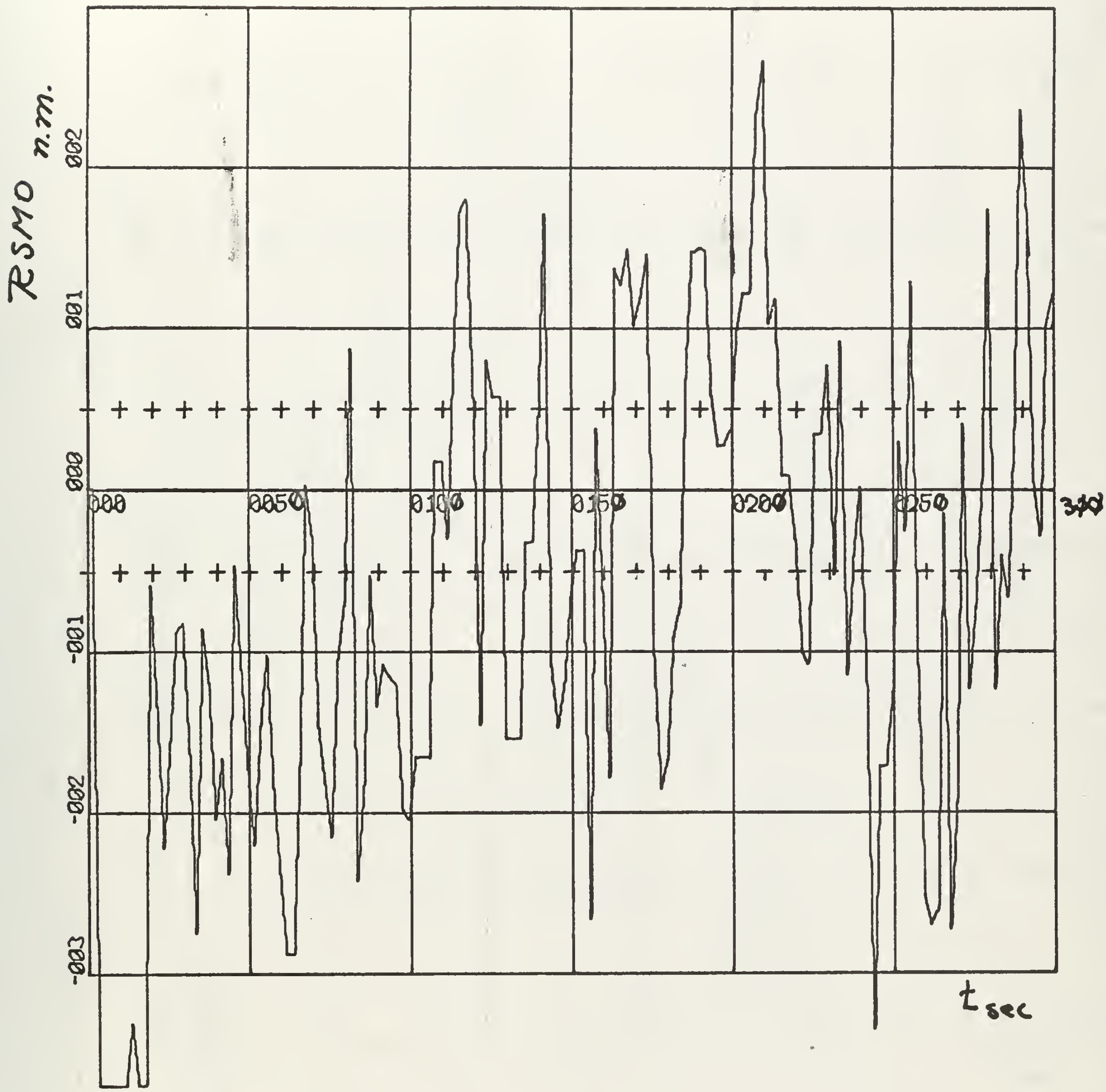


X-SCALE = 2.00E+01 UNITS/INCH.
Y-SCALE = 2.00E+00 UNITS/INCH.

GENTZ ND PLANE SMOOTHED POSITION RUN 3A

[redacted]

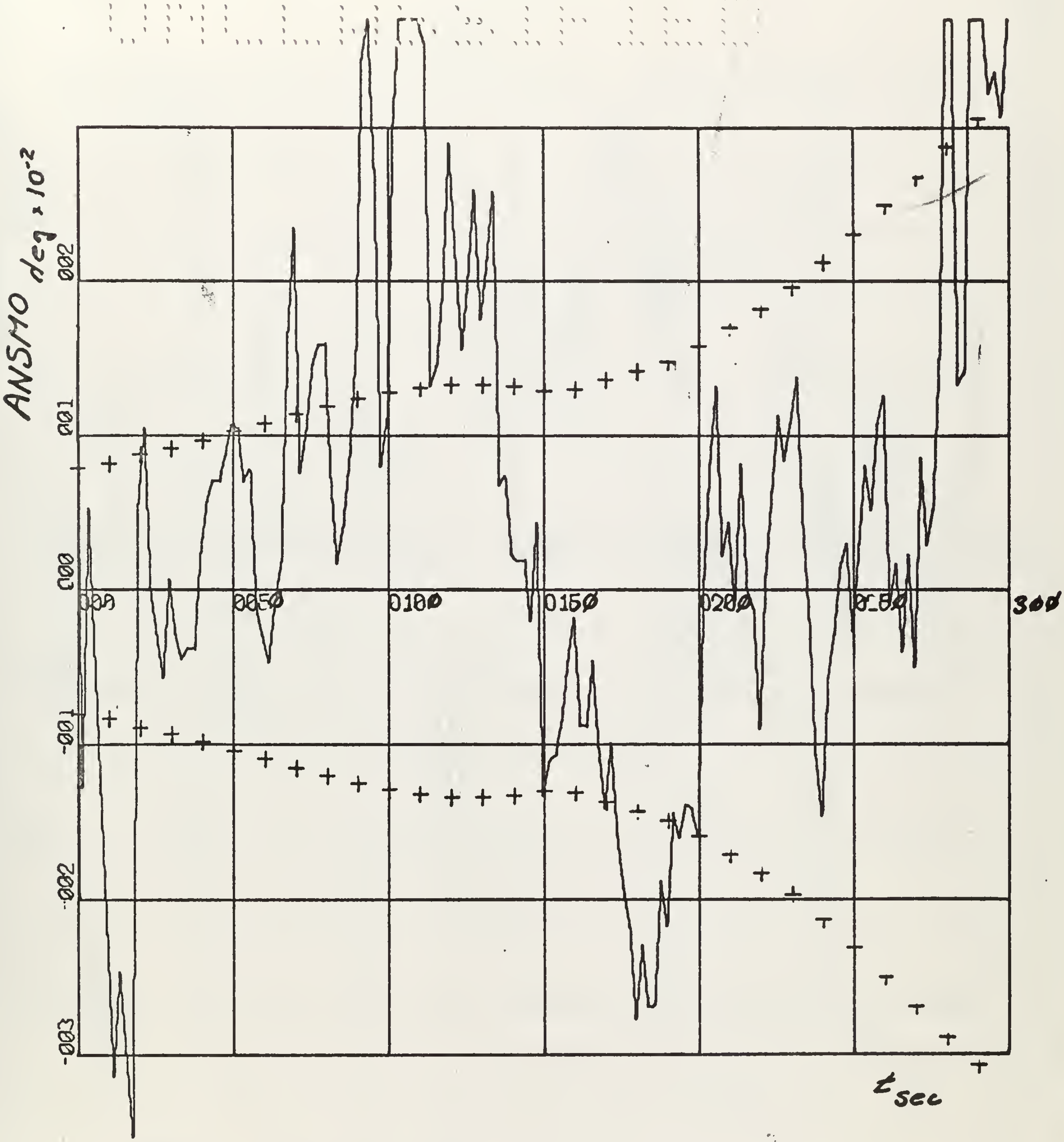
FIGURE 39



X-SCALE = 5.00E+01 UNITS/INCH.
Y-SCALE = 1.00E+00 UNITS/INCH.

GENTZ RANGE SMOOTHING RESULTS RUN 3A

FIGURE 30



X-SCALE = 5.00E+01 UNITS/INCH.
Y-SCALE = 1.00E-02 UNITS/INCH.

GENTZ NORTH SMOOTHING RESULTS RUN 3A

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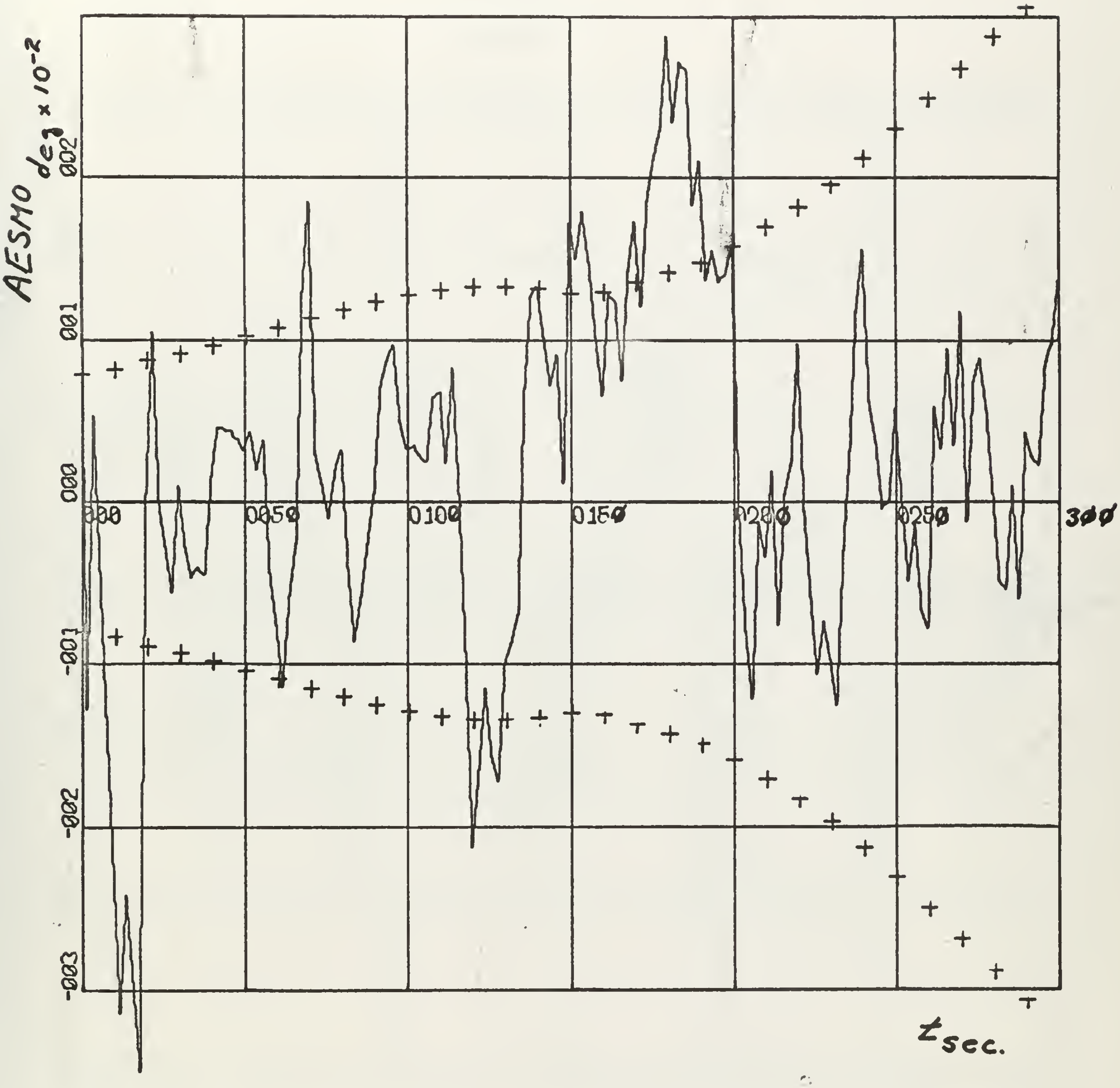
FIGURE 31



X-SCALE = 5.00E+01 UNITS/INCH.
Y-SCALE = 1.00E-02 UNITS/INCH.

GENTZ EAST SMOOTHING RESULTS RUN 3A

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[redacted]

[redacted]

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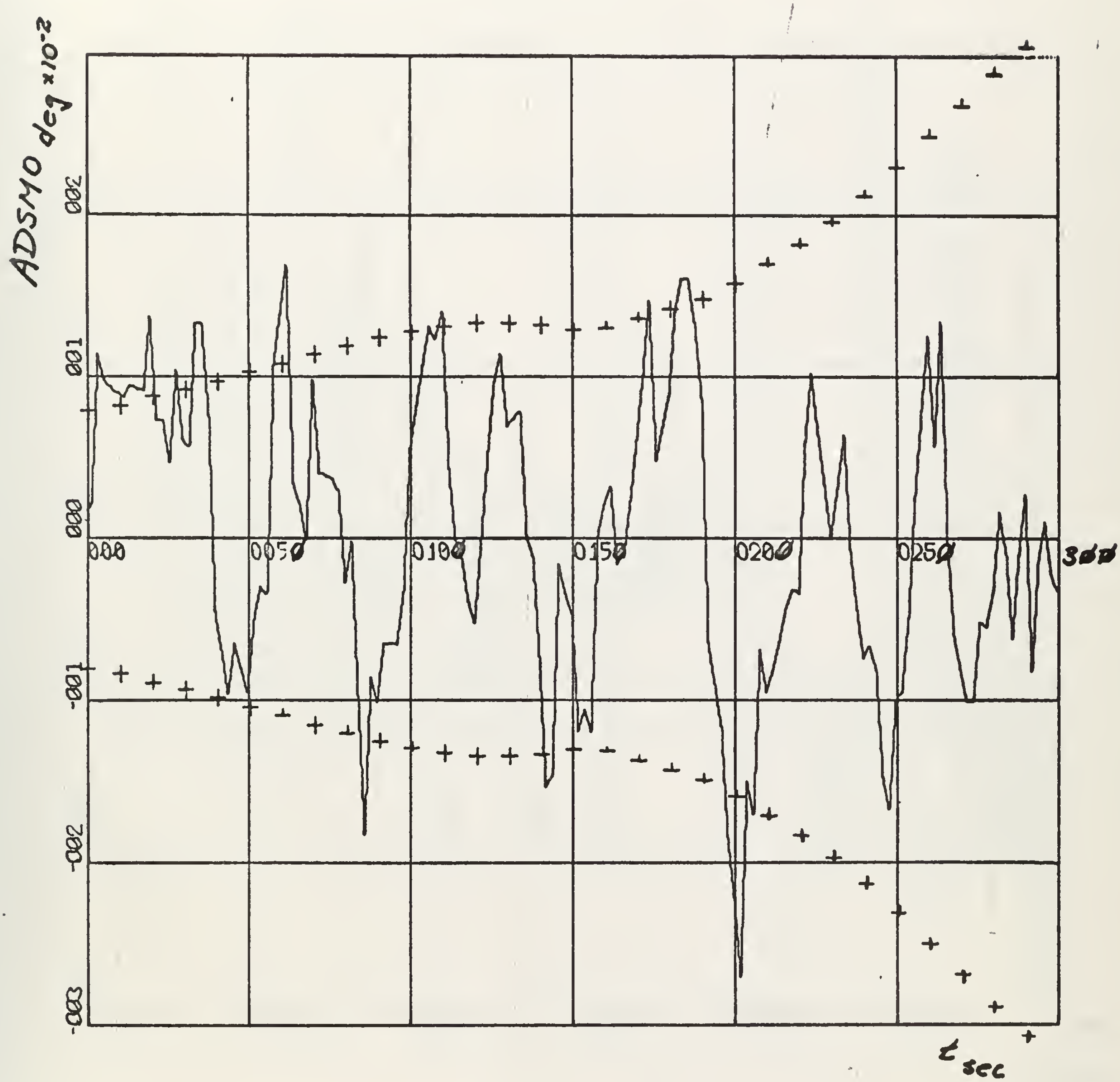
FIGURE 32



X-SCALE = 5.00E+01 UNITS/INCH.
Y-SCALE = 1.00E-02 UNITS/INCH.

GENTZ DOWN SMOOTHING RESULTS RUN 3A

[redacted]

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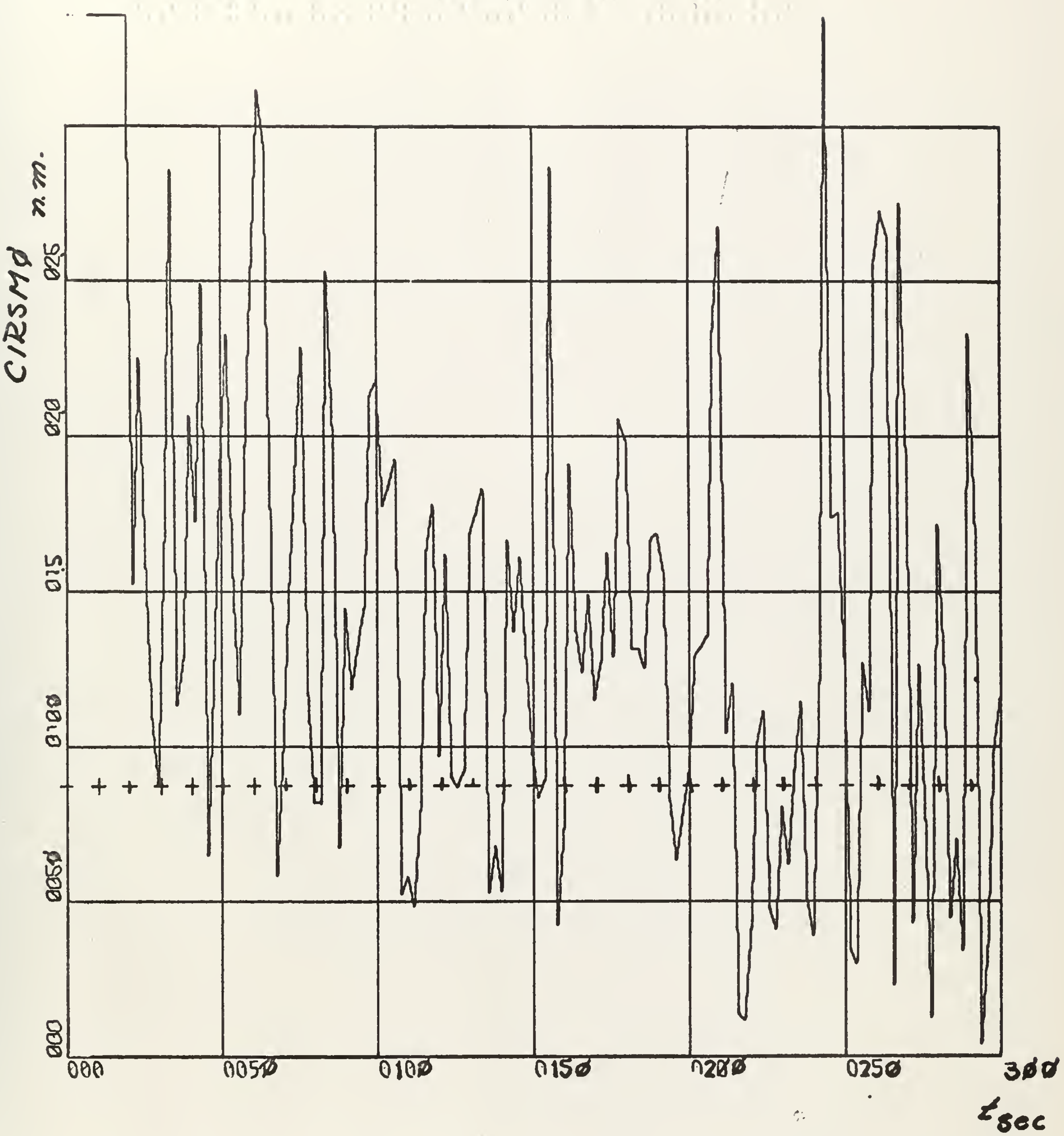
FIGURE 33



X SCALE = 5.00E+01 UNITS/INCH.
Y SCALE = 5.00E-02 UNITS/INCH.

GENTZ 3D RMS SMOOTHING RESULTS RUN 3A

[redacted]

Thesis
G2626
c.1
Gentz
Investigation of optimum smoothing in a track-while-scan radar using three dimensional simulation.